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# THESIS

EFFECTS OF STORM-RELATED PARAMETERS ON
THE ACCURACY OF THE NESTED
TROPICAL CYCLONE MODEL

by

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March 1986

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# Effects of Storm-related Parameters on the Accuracy of the Nested Tropical Cyclone Model

by

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Lieutenant, United States Navy
B.A., University of Washington, 1979

Submitted in partial fulfillment of the requirements for the degree of

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# ABSTRACT

The performance of the Nested Tropical Cyclone Model (NTCM) for 542 track forecasts in the western North Pacific during 1981-1983 is evaluated with respect to five storm-related parameters: intensity, 12-h change in intensity, latitude, longitude and size. This study is intended to aid the operational forecaster in deciding when to use the NTCM based on storm-related parameters at the forecast time. The storm-related parameters are divided into three subsamples (about 180 in each) and the forecasts are evaluated in terms of the mean forecast error, median forecast error and systematic (zonal and meridional) error. Cross-track (CT) and along-track (AT) components are computed relative to a CLImatology and PERsistence (CLIPER) track. A scoring system (M) that assesses penalty points for forecasts in incorrect terciles is used to compare the accuracy of the NTCM and CLIPER forecasts within the subsamples. For the entire sample, the NTCM has a slow bias, especially at the 12- through 36-h forecast periods. It also performs better for storms with initial latitudes south of 13° N and initial longitudes west of 129° E. For very large storms, the NTCM forecasts have both left-of-track and westward biases which indicate problems of the NTCM in predicting recurvature of such systems. The NTCM (which has a 60-kt bogus) forecasts for storms with initial intensities between 50 and 75 kt have much lower CT/AT M scores and smaller forecast errors than the subsamples with initial intensities less than 50 kt or greater than 75 kt.

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# I. INTRODUCTION

The enormous destructive potential of intense tropical cyclones is well known. The high winds, heavy seas and torrential rain that accompany these systems have caused great loss of life and damage to property at sea and ashore. Thus, it is not surprising that accurately forecasting the movement of tropical cyclones is of primary importance to civilian and military organizations in affected regions. Recognizing this, the Commander in Chief, U.S. Pacific Command has given an improved forecast capability the highest priority for tropical cyclone research objectives within the Department of Defense (DOD) (COMNAVOCEANCOM,1984). Especially important are long-range (48- to 72-h) forecasts, which are required by operational commanders who must consider movement of ships and aircraft to avoid damage to DOD assets. Civilian authorities also need advance warning to implement public disaster preparedness measures. Noting this requirement for increased accuracy in track forecasting, the United States Seventh Fleet Commander has levied a requirement on the Joint Typhoon Warning Center (JTWC) in Guam to achieve maximum forecast errors of 50, 100, and 150 nautical miles (n.mi.) for 24, 48, and 72 h respectively.

During the past decade, the rate of improvement in tropical cyclone track forecasting has not been as rapid as hoped. It is generally accepted that a "plateau" has been reached in the annual 24-h forecast error statistics (Elsberry, 1984). Improvements in 72-h forecasts have been realized, but only in some tropical cyclone regions (Thompson, et al., 1981). Furthermore, while some components of the tropical cyclone warning system have been improved, others have been degraded. For example, the introduction and advancement of satellite surveillance techniques have not compensated for the loss of data due to the reduction in conventional observations and in reconnaissance flights (Elsberry, 1984).

The most important recent development has been the implementation of new dynamic forecast models to predict tropical cyclone tracks (Elsberry, 1983). The U.S. Navy two-way interactive nested tropical cyclone model (NTCM) was originally developed by Harrison (1973). It has been tested with operational data by Harrison (1981), Harrison and Fiorino (1982), Fiorino et al. (1982) and Peak and Elsberry (1984). These tests with a large number of cases indicate that the NTCM has high potential for good performance at 48 and 72 h (Fiorino, 1985). However, problems with consistency in the NTCM tracks have limited its value as an operational forecast tool. JTWC recently evaluated NTCM track predictions in the western North Pacific during the 1984 tropical cyclone season and found that the NTCM-predicted cyclone movement averaged 40 percent less than that observed (Sandgathe, 1985). This slow bias significantly hampers the decision-making process of the typhoon duty officer (TDO) because the "decision points" in the forecast track (recurvature, etc.) are forecast too late.

The primary objective of this thesis is to determine how storm-related parameters affect the NTCM-predicted track. This knowledge may provide valuable information to the forecaster concerning the veracity of a particular NTCM forecast based on certain storm-related conditions observed at the time the tropical cyclone warning is issued. An example in which such knowledge may have been useful is Supertyphoon Abby in 1983. Fiorino (1985) suggests that the NTCM and virtually all of the other forecast aids were incorrect because Abby was such a large storm (radius of 30-kt winds greater than 300 n.mi.). By contrast, Typhoon Ike (1984), a very small storm (radius of 30-kt winds less than 100 n.mi.), was also incorrectly forecast by NTCM. In addition to size, the storm-related parameters of intensity, past 12-h intensity change, and position are studied to determine what relationships exist between these parameters and the respective NTCM forecasts. The intensity and intensity change parameters are chosen because the NTCM includes a time-independent bogus storm of 60-kt intensity in the initial conditions.

Knowledge of the NTCM performance characteristics is essential in making the correct decision to accept or reject a particular NTCM forecast. Such performance characteristics of the NTCM, based on certain storm-related parameters, are described herein. In addition, the methodology used in this study, while developed specifically for the NTCM, can (and should) be applied to other objective tropical cyclone forecast aids. Similar studies will be useful to compile "rules of thumb" for each aid under various storm-related conditions. Given a set of such rules and the initial storm-related parameters, a forecaster should be able to make a better and quicker evaluation of the relative merit of the track forecasts from each objective aid. In a broader context, the methodology of this study may be used to provide the objective measures of storm-related or synopticity factors to build a "decision-tree" algorithm. The "decision-tree" algorithm suggested by Peak and Elsberry (1985) selects the objective aid that is most appropriate to each forecast situation, based on a large number of synopticity and storm-related factors. The tree-structured approach to forecasting is expected to reduce forecast errors, improve training and guidance for inexperienced TDO's, and provide a detailed record of the decision process for post-storm analysis. Because of the myriad of possible storm-related and synopticity factors, and the numerous existing objective aids to be evaluated, much more work must be done before the "decision-tree" concept becomes an operational reality.

## II. THE NESTED TROPICAL CYCLONE MODEL

The NTCM was originally developed by Harrison (1973) to demonstrate the concept of grid-nesting with two-way interactive boundaries. After early tests of the model had shown considerable promise (see Harrison, 1981), its forecasts have been received on a regular basis by the JTWC since 1979. Different versions of the NTCM were used in subsequent seasons as modifications were made to decrease the model forecast errors (Fiorino, 1985). The forecasts analyzed in this study are from the operational model during 1983. The 1981 and 1982 storms were re-run by M. Fiorino using this version to provide a homogeneous data set.

The NTCM is a three-layer model with a nested, moving grid that provides high resolution in the vicinity of the cyclone circulation. The inner grid remains centered on the storm position as it moves within the 6600 km x 4900 km outer region. The inner grid has a 1230 km x 1230 km domain with 41 km resolution. The coarse grid resolution is 205 km, which gives a five to one reduction at the interface. The NTCM does not include topographic effects. A simple analytic heating function centered on the surface cyclone is used to maintain the cyclonic circulation. The north-south boundaries of the outer grid consist of free-slip walls while cyclic continuity is assumed in the east-west direction. The inner grid has two-way interactive boundaries which allows cyclone circulation in the inner grid to influence the environmental flow and vice versa. The model uses centered time and space differencing techniques.

The NTCM is initialized from the global band tropical analysis fields generated by the Fleet Numerical Oceanography Center (FNOC). Because of the channel boundary conditions, the NTCM can be integrated independently of other models or inputs following initialization from the analysis fields. This feature is particularly desirable from the standpoint of operational timeliness (Elsberry, 1979).

The NTCM uses a reverse balance initialization technique for wind and geopotential fields (Harrison and Fiorino, 1982). The tropical cyclone is simulated by a bogus circulation imposed on the fine grid at the observed location of the storm. The initial intensity of the storm is always 60 kt. The streamfunction field is calculated from the vorticity which is obtained from the analyzed wind field. Divergence is allowed in the solution of the nonlinear balance equation for the geopotential height field. The balanced geopotential values are then interpolated from the coarse grid to the edge of the fine grid, and similar balancing is performed on the fine grid. Values at the coincident points on the fine grid are then substituted for the interior of the coarse grid solution. The entire initialization process is repeated two or three times to ensure that both grids have converged to approximately the same balanced initial fields. Initialization of the coarse grid and treatment of the input data were modified for the 1983 season (Fiorino, 1985) to improve the consistency between the mass and wind fields, especially near the channel boundaries.

The basic philosophy of the model is to provide good, long range track predictions in a timely manner for use by an operational forecaster. This study is an attempt to analyze and understand the performance characteristics of the NTCM as a function of storm-related parameters using a large data set. It will be shown that the performance of the model can be related to the values of these parameters so that an operational forecaster can use this information to help decide whether or not to use the NTCM.

## III. THE DATA SET

### A. NTCM, CLIPER AND BEST-TRACK POSITIONS

The position data set consists of 542 tropical cyclone cases from the western North Pacific during 1981, 1982 and 1983 in which track forecasts are available up to 72 h. These data include the NTCM and the western North Pacific CLImatology and PERsistence model (CLIPER) forecasts as well as the verifying best-track positions in 12-h increments for all 542 cases. The data set, kindly provided by Mr. Michael Fiorino of the Naval Environmental Prediction and Research Facility (NEPRF), represents the largest homogeneous data set used to analyze the performance of the NTCM. Even so, the 542 cases represent only about one-fourth of the approximately 2200 tropical cyclone warnings issued in this region from 1981 through 1983 . The reason for this is twofold:

1. The NTCM was run only once every 12 h for seasons 1981and 1982 (every 6h for 1983), whereas the JTWC issues warnings every 6h; and

2. All NTCM forecasts without verifying positions to 72 h were excluded.

The 72-h CLIPER forecasts, also provided by M. Fiorino, were run for the same cases as the NTCM. The resultant data set is homogeneous since the NTCM and CLIPER models have track predictions to 72 h for each of the 542 cases and verifying data (best track) are available for each forecast position.

The western North Pacific CLIPER, which was developed by Xu and Neumann (1985), uses regression equations to relate future storm positions to initial position, past 12- and 24-h positions, initial intensity, and Julian date. The equations were derived for storms south of 35°N and west of 150°E which occurred during the months of May through December. The forecasts to 24 h rely heavily on persistence, and more on climatology at the 48- and 72-h forecast periods. The CLIPER track is selected as a reference in calculating the cross-track (CT) and along-track (AT) error components for both the NTCM and best-track positions (see chapter IV). The reason for using CLIPER is that it is a statistical forecast scheme that should be free of any significant bias with respect to the actual storm track.

## B. STORM-RELATED PARAMETERS

The storm latitude, longitude, intensity, previous 12-h change in intensity and radius of 30-kt winds are selected as the storm-related parameters to be used as predictors. The data are taken from the JTWC warnings and correspond to the initial times of the 542 NTCM and CLIPER forecasts. These five parameters are chosen for two reasons. First, when taken from the JTWC warnings, they represent the real-time data that are available to the TDO at the time the NTCM is run. Second, these storm-related parameters are expected to have some degree of influence on the future storm track (Elsberry, 1984).

The samples of each of the five storm-related parameters are partitioned into equal-sized terciles. The cutpoints between the terciles are then used to segregate the corresponding sample of NTCM and CLIPER forecasts into three subsamples. Various error statistics (see chapter IV) are computed for each subsample of forecasts and examined to determine differences in NTCM forecast performance. The histograms for each of these parameters (with the locations of the tercile cut points) are provided in Figs. 1a-1e.

The distribution of initial latitudes for the sample (Fig. 1a) is slightly skewed with maximum frequencies near the lower cutpoint (between 12°N and 13°N) and the mean latitude (15.5°N) near the upper cutpoint (between 16°N and 17°N). There are 183, 177 and 182 cases for the "southern", "central" and "northern" areas. In the histogram of initial longitude (Fig. 1b), the lower cutpoint is between 128°E and 129°E and the upper cutpoint between 139°E and 140°E. The distribution of initial longitudes also appears slightly skewed, with the maximum frequency near the lower cutpoint. There are 169, 186 and 187 cases in the "western", "middle" and "eastern" areas.

The histogram of initial intensities (Fig. 1c) is skewed toward the lower intensities. The width of the cells in the histogram is 5 kt because intensities on the JTWC warnings are issued in 5-kt increments. The cutpoints, which are located between 45 and 50 kt and between 75 and 80 kt, divide the data into subsamples which shall be referred to as "weak", "moderate" and "intense" tropical cyclones. The number of cases in each subsample is 182, 182 and 178 respectively. The histogram of the previous 12-h intensity change can be separated into "weakening", "developing" and "rapidly developing" subsamples using the cutpoints between 0 and 5 kt and between 10 and 15 kt (Fig. 1d). The number of cases in these subsamples are 190, 169 and 99, respectively. The sample can not be partitioned equally because the majority of the cases falls into just a few of the cells, and the cells can not be smaller than 5 kt of 12-h intensity change. The size of the sample is consequently reduced to 458 because the intensity differences can not be computed for the first warning of a tropical cyclone.

Noticeable "spikes" in the histogram of the radii of 30-kt winds (Fig. 1e) occur at 30, 100, 150 and 300 n.mi. When a warning gives two semicircles of wind radii, the larger of the two is used. In addition, tropical cyclones ≤ 30 kt are assigned a radius of 30 n.mi. The radius of 30-kt winds is often rather subjective as peripheral data from aircraft reconnaissance may not be available. These data were manually extracted by Mr. Charles Leonard of the Department of Meteorology at NPS from over 2200 warning messages issued by JTWC. The cutpoints are located between 105 and 110 n.mi. and between 205 and 210 n.mi., which separates the sample into "small", "medium" and "large" tropical cyclones. The number of cases in the three subsamples are 186, 181 and 175 respectively.

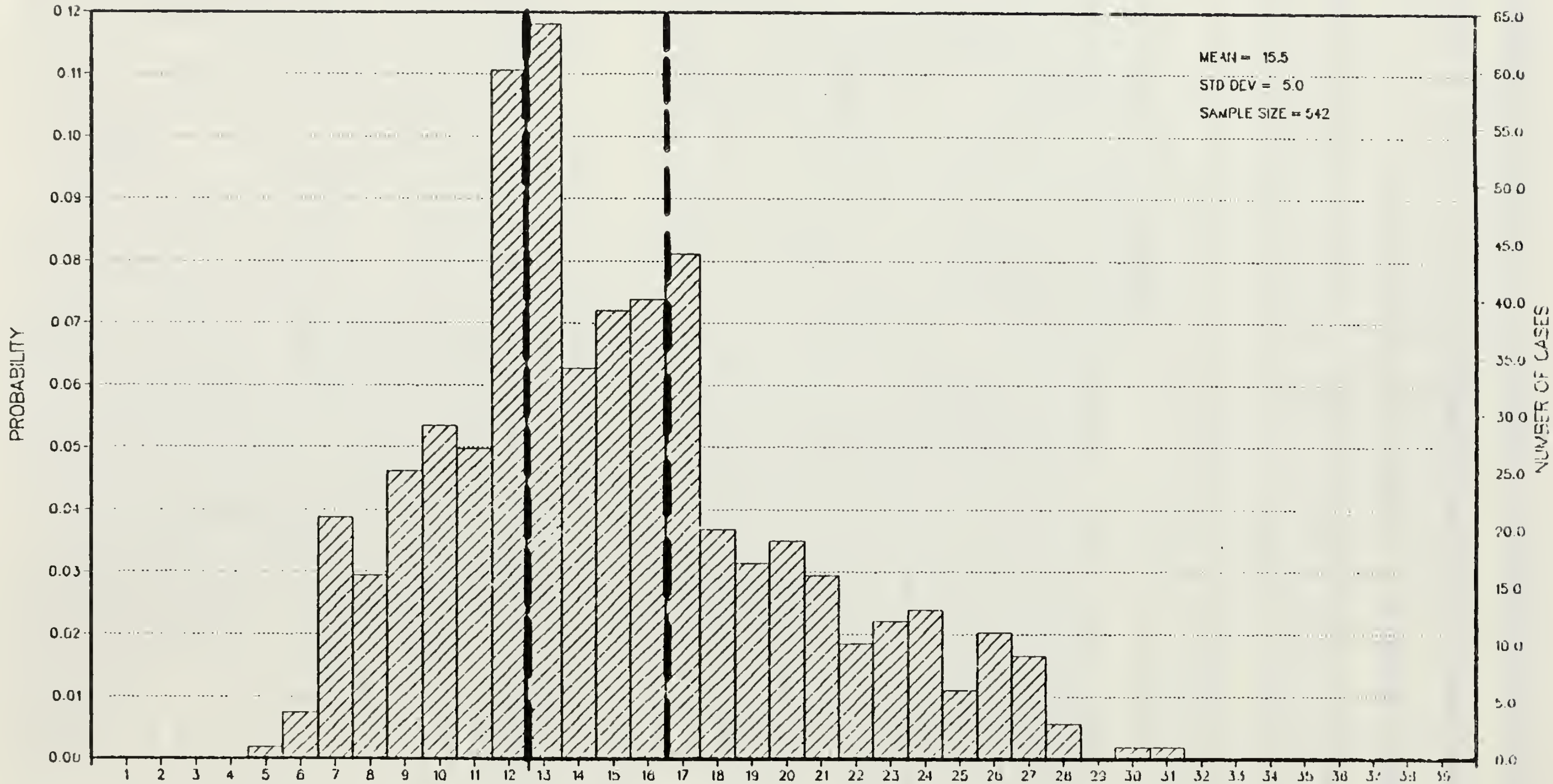


Figure 1a. Distribution of initial latitudes during 1981-83. Dashes indicate tercile cutpoints.

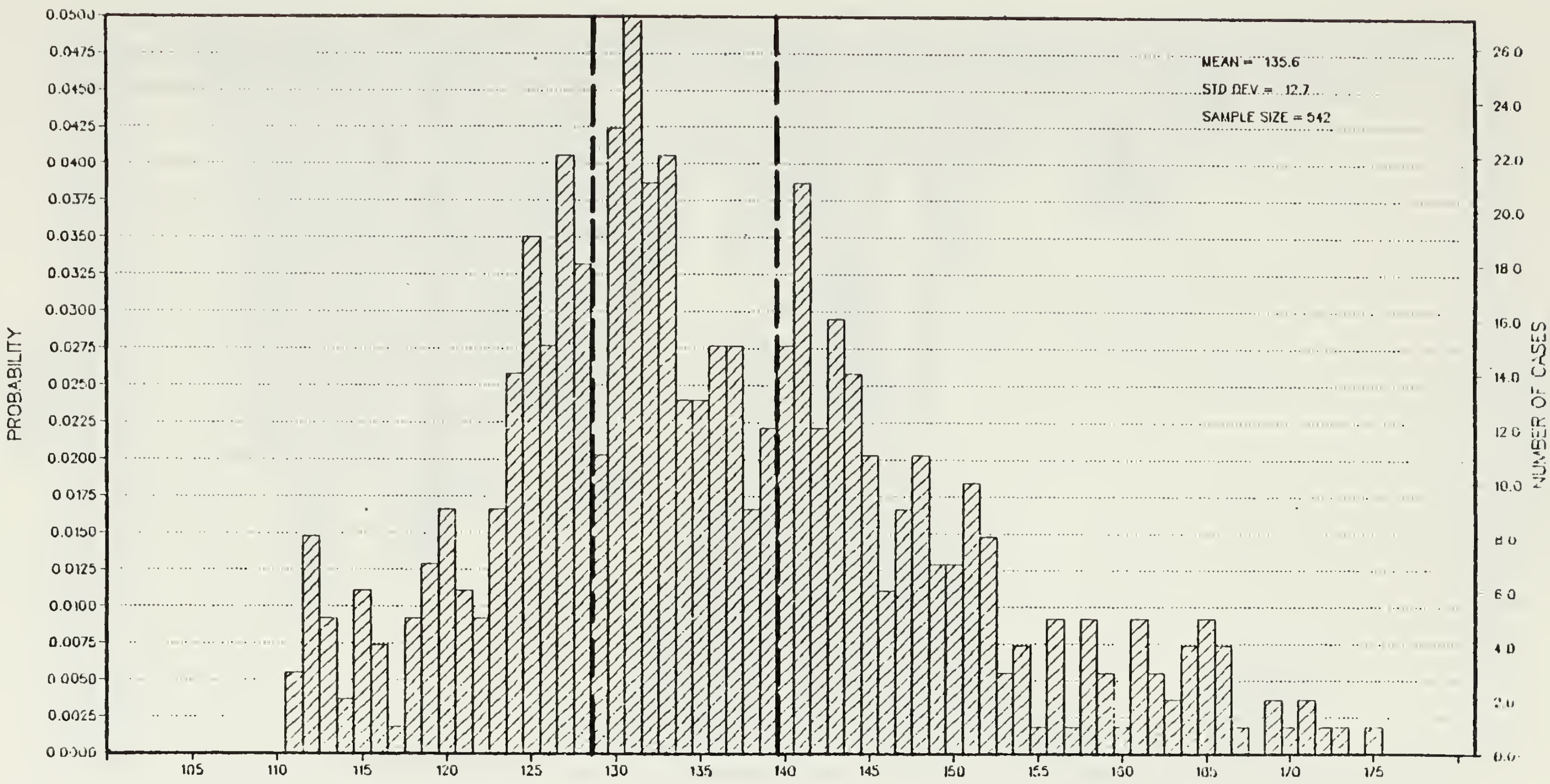


Figure 1b. Similar to Fig. 1a except for initial longitudes.

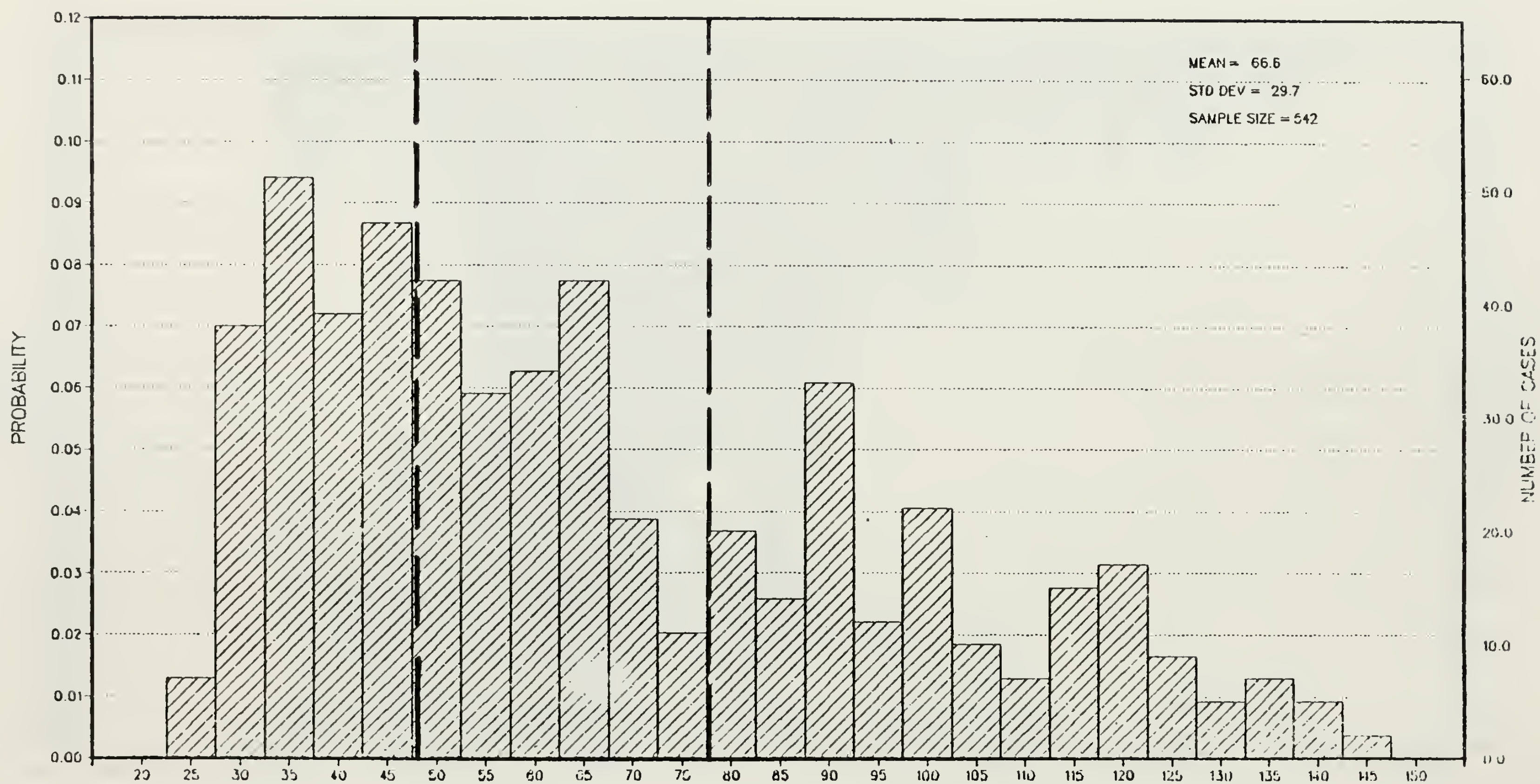


Figure 1c. Similar to Fig. 1a except for initial intensity (kts).

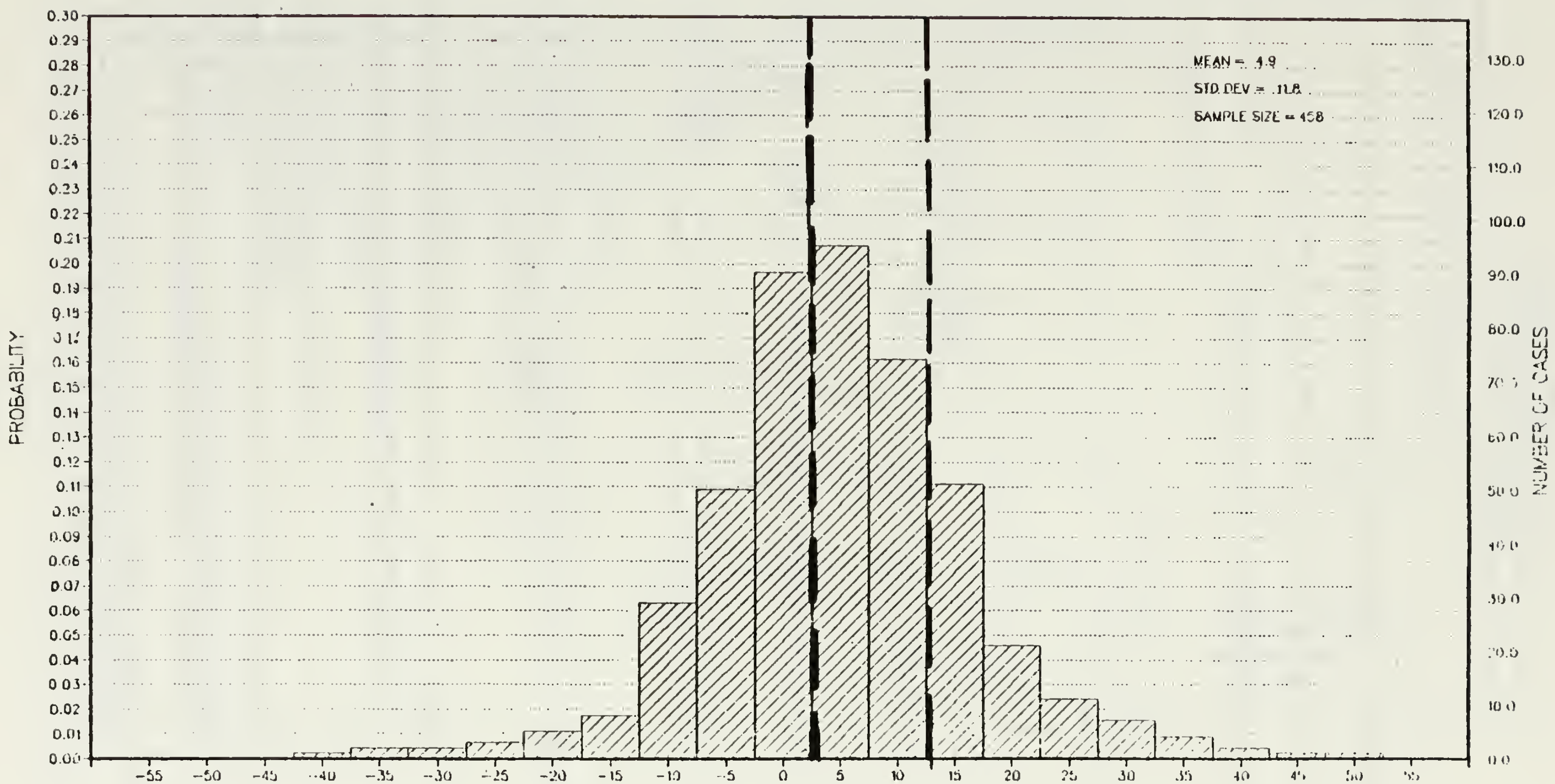


Figure 1d. Similar to Fig. 1a except for previous 12-h intensity change (kts).

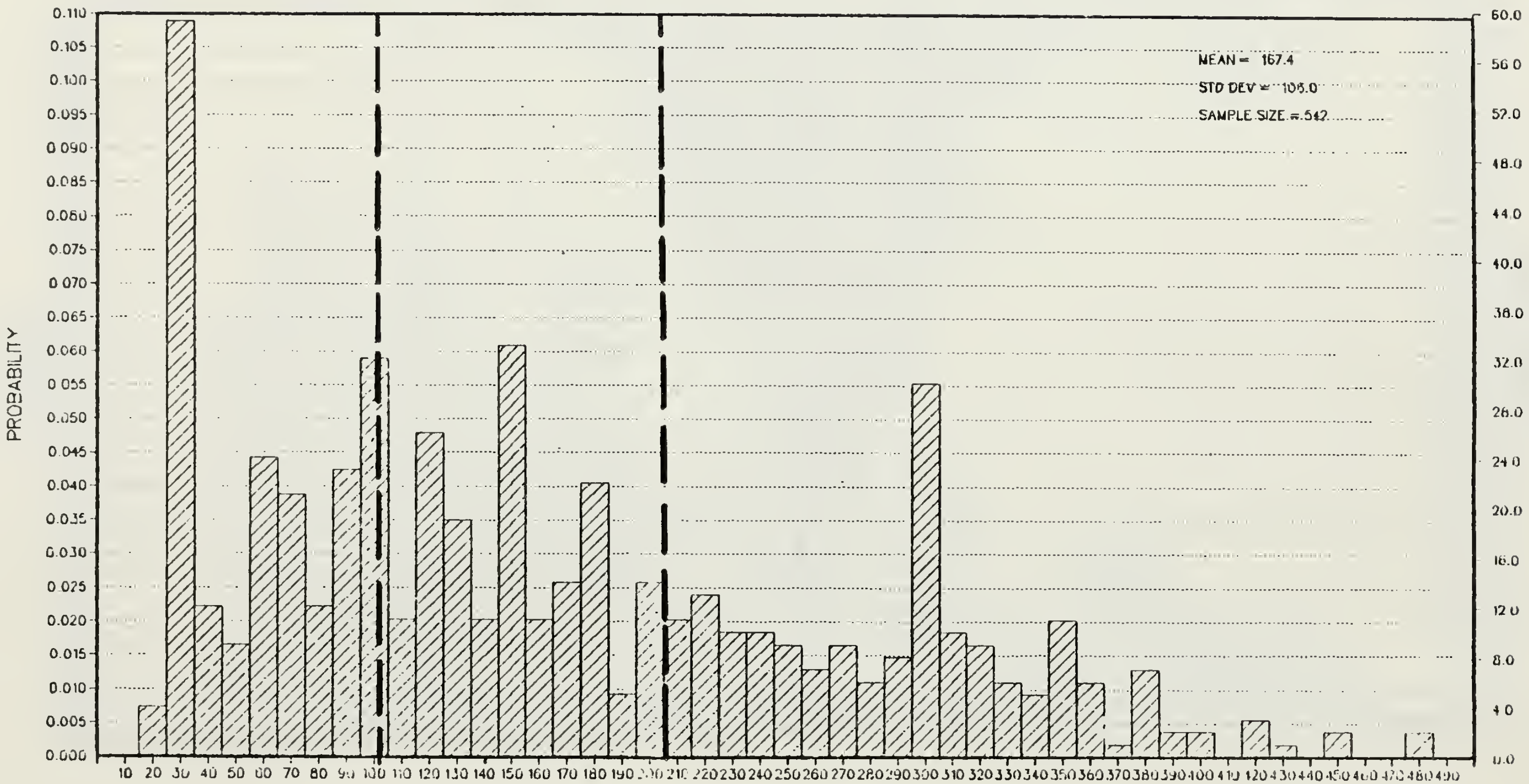


Figure 1e. Similar to Fig. 1a except for radius (n.mi) of 30-kt winds.

## IV. ERROR STATISTICS

### A. MEAN AND MEDIAN FORECAST ERRORS

A measure of accuracy commonly used for tropical cyclone track forecasts is the "forecast error", which is defined as the great circle distance between the forecast and verifying position (Fig. 2). The mean forecast error is simply the sum of the errors divided by the number in the sample.

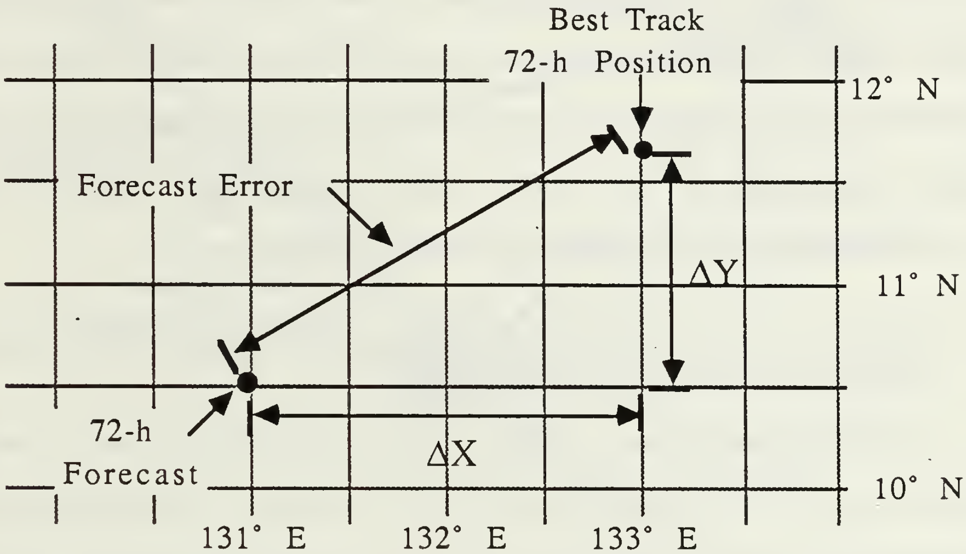


Figure 2. Definition of forecast and systematic error components (ΔX and ΔY). In this example, both ΔX and ΔY are negative.

Because the distribution of the forecast errors in a sample is bounded on one side by zero and unbounded on the other, many studies use the "median forecast error" which is the value of the $50^{th}$ percentile in the distribution.

The mean and median forecast errors at 12, 24, 36, 48, 60 and 72 h for the NTCM and CLIPER (verified relative to best-track positions) are computed for the total sample (542 cases) and for each subsample stratified by different values of storm-related parameters. The unit used for these and all other error components is kilometer (km).

## B. SYSTEMATIC ERRORS

Another measure of error for tropical storm track forecasts is the systematic error. The systematic error components, $\sum X$ and $\sum Y$, are simply the zonal ($\Delta X$) and meridional ($\Delta Y$) errors averaged over the sample of forecasts (Fig. 2). The error components are calculated for each 12-h forecast period to 72 h. The systematic error components are useful in determining the presence (or absence) of an error bias in the sample. For example, a monotonic increase or decrease throughout the forecast period indicates a systematic error which might be statistically removed (Peak and Elsberry, 1982). The sign convention for this study is positive if the forecast position is north ($+\sum Y$) or east ($+\sum X$) of the best-track position. The results of the systematic, mean and median error statistics for the NTCM and CLIPER samples are discussed in chapter V (Tables 3 and 4).

## C. CROSS-TRACK AND ALONG-TRACK ERROR COMPONENTS RELATIVE TO EXTRAPOLATED CLIPER FORECASTS

Forecast errors are also presented as cross-track (CT) and along-track (AT) components. The objective of the CT/AT system is to provide information to the forecaster about the movement and direction of the storm relative to a standard forecast aid such as persistence or climatology (Elsberry and Peak, 1986). The mean and median forecast errors give only the magnitude of the error relative to the actual position and the systematic error gives the average of the zonal and meridional error components. On the other hand, the CT/AT errors also provide information about the direction of the forecast in a storm-oriented reference frame. Elsberry and Peak (1986) evaluated tropical cyclone aids based on CT and AT components relative to an extrapolated track based on warning positions at the initial (00) and past 12-h time periods. They interpreted the CT components as turning motion and the AT components as acceleration or deceleration. This directionality aspect gives important information to the forecaster that is not available from the other error measures.

The CT/AT scheme used in this study differs from that of Elsberry and Peak (1986) in that the CT and AT components for the NTCM or best-track positions for each forecast period (24, 48, 72 h) are calculated relative to the CLIPER forecast at the corresponding time. For example, the CT/AT at 72 h is calculated relative to a line connecting the 72 and 60 h CLIPER positions (Fig. 3).

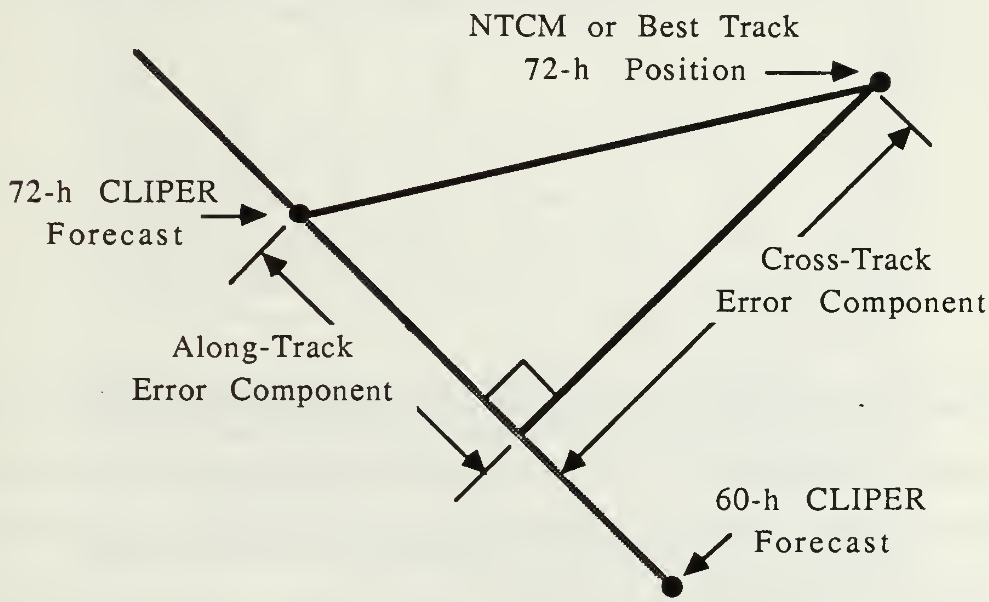


Figure 3. Definition of cross-track (CT) and along-track (AT) components at 72 h relative to an extrapolated track based on CLIPER positions at 72 and 60 h. In this example, CT is positive (right) and AT is negative (slow) with respect to the CLIPER track.

The perpendicular distance from the NTCM or best-track position to the extrapolated track is the cross-track component, with positive values to the right of the track and negative to the left. The distance along the extrapolated track from the CLIPER position to the perpendicular from the NTCM or best-track position is the along-track component. Positive (negative) AT values occur if the perpendicular meets the track ahead (behind) the corresponding CLIPER position.

The CT/AT components of the best track are computed for the entire best-track sample at 24-, 48- and 72-h forecast periods. The means and standard deviations of the distributions for each forecast period are shown in Table 1.

Table 1

Means (x) and standard deviations (σ) of the 24-, 48- and 72-h CT and AT components (km) for the total sample of best-track positions (relative to CLIPER forecasts).

| | 24 h | | 48 h | | 72 h | |
|---|---|---|---|---|---|---|
| | $\bar{x}$ | σ | $\bar{x}$ | σ | $\bar{x}$ | σ |
| CT | -22 | 164 | -29 | 340 | -41 | 574 |
| AT | -66 | 165 | -179 | 377 | -276 | 594 |

Notice that the mean values of the 24-, 48-hand 72-h CT errors are all very close to zero, which indicates that the best-track CT components are not biased with respect to the CLIPER track. This result is not surprising because a statistical scheme such as CLIPER should have no bias relative to the overall mean position. It can also be seen that the standard deviation increases with time. The symmetric properties of the CT sample are evident in the histograms for the samples of the three time periods (Figs. 4a-c). The tercile cutpoints are indicated on the histograms by dashed lines. The cutpoints of the 24-h CT distribution (Fig. 4a) are at -75 km and 50 km, which is almost exactly centered about the mean (-22 km). The 48-h CT (Fig. 4b) cutpoints are at -125 km and 125 km, and are also symmetric about the mean. The same properties can be seen in the 72-h sample (Fig. 4c), which has cutpoints at -200 km and 200 km. The nearly symmetric distribution of best-track CT error components around the mean CLIPER track supports the use of CLIPER as a referencing system because it is more likely to provide an orientation with respect to the mean track of the tropical cyclone. The terciles have been labeled left (L),

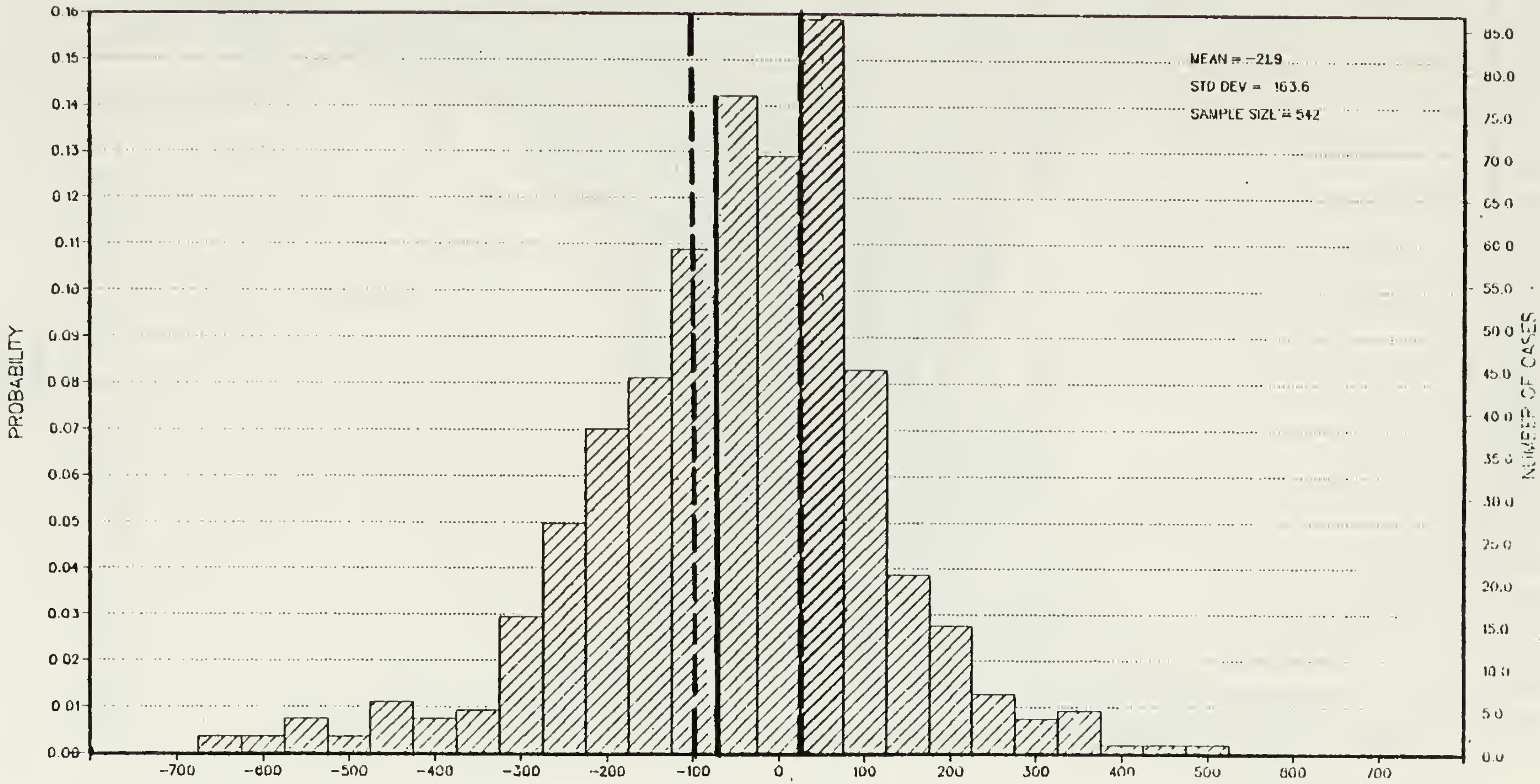


Figure 4a. Distribution of best-track 24-h cross-track (CT) error components (km). Each point on abscissa indicates of the respective histogram cell. Dashes indicate approximate locations of tercile cutpoints.

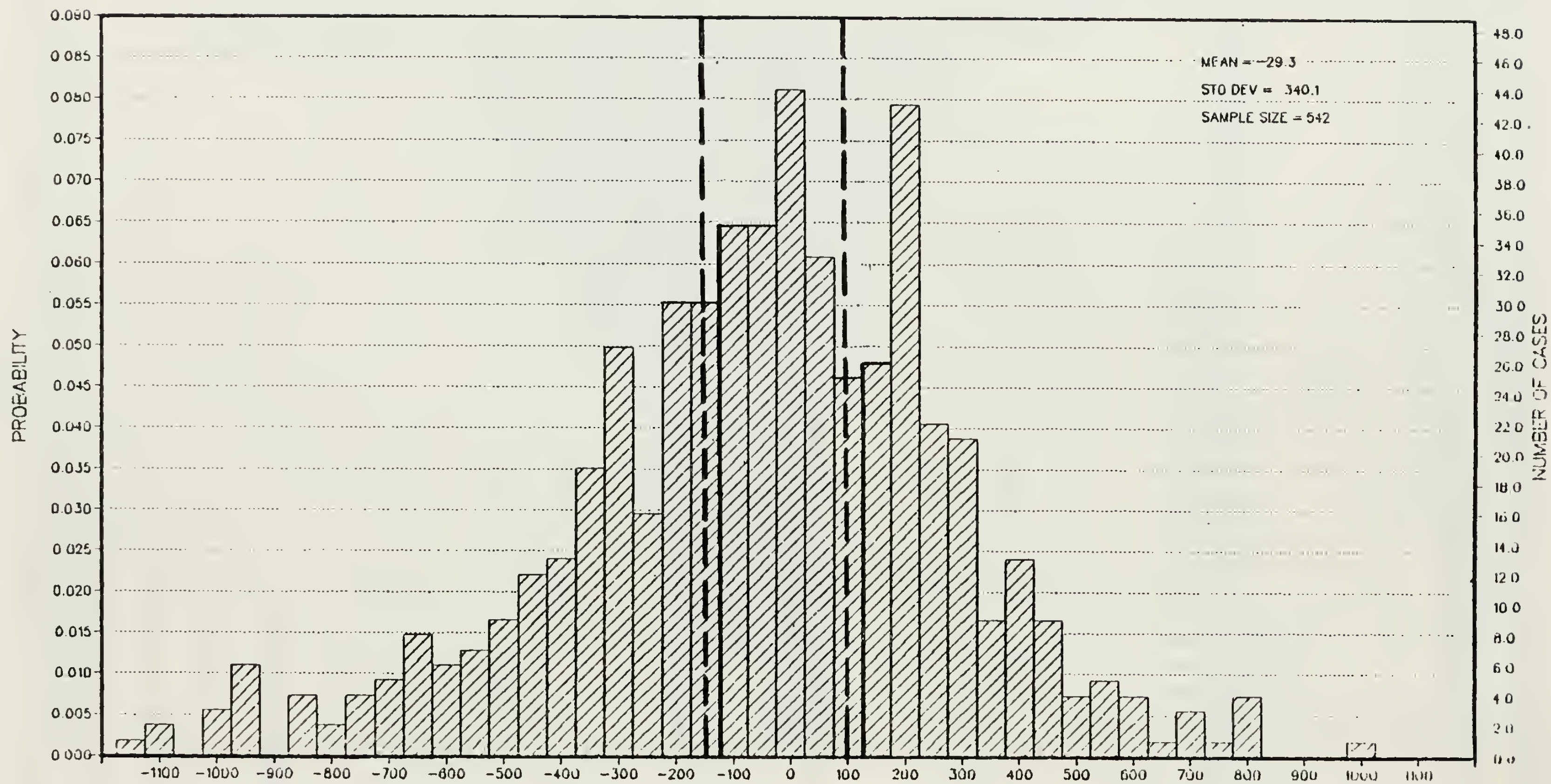


Figure 4b. Similar to Fig. 4a except for 48-h CT error components.

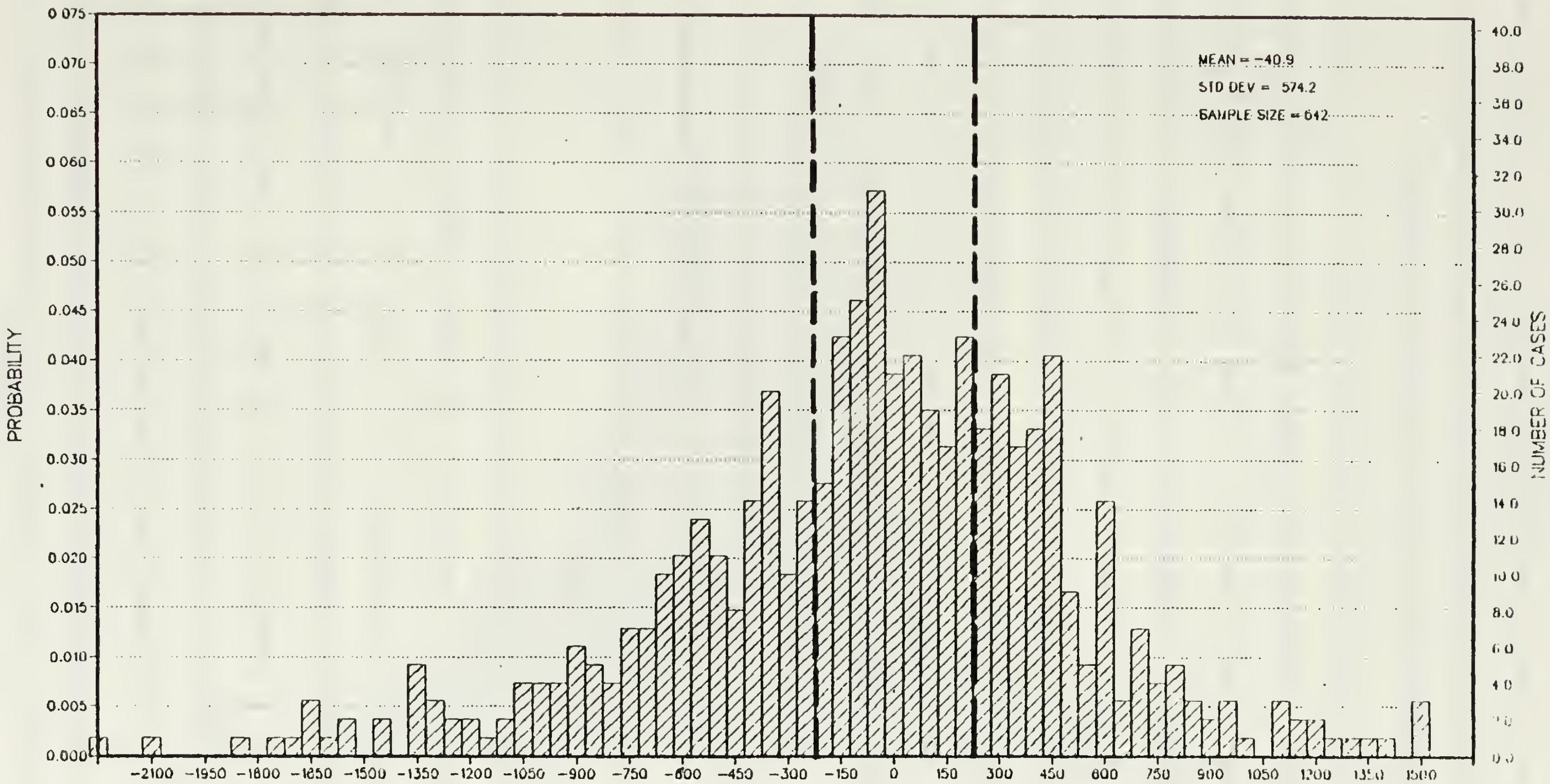


Figure 4c. Similar to Fig. 4a except for 72-h CT error components.

center (C) and right (R) according to the distributions of the best-track CT error components for the 24-, 48- and 72-h distributions. These three (L, C and R) categories are used to compare NTCM forecasts to the best-track positions.

The AT distributions exhibit characteristics similar to those of the CT distributions discussed above. The values of the standard deviation for the AT distributions (Table 1) are very close to those of the CT for all three time periods. The AT histograms (Figs. 5a-c) resemble the CT histograms (Figs. 4a-c) in that they are also very symmetric about the mean. As with the CT error components, the terciles are marked on Figs. 5a-c and have been named to indicate the position with respect to the extrapolated CLIPER track: slow (S) , center (C) and fast (F). However, the negative mean ( x ) values (Table 1) of -66, -179, and -276 km indicate that best-track positions are consistently "slow" with respect to the extrapolated CLIPER track (or, that CLIPER is "fast" compared to the best-track). This results from the fact that given the same initial position and identical speed of movement, any deviation in direction of movement from the reference ( past 12 h extrapolated CLIPER) track will produce an apparent "slow" AT error component. This is one of the shortcomings of attempting to define a storm-oriented coordinate system (Neumann and Pelissier, 1981).

The primary advantage in using the CLIPER forecast rather than an extrapolated track from warning and -12 h positions (as was done in Elsberry and Peak, 1986) as the reference for CT/AT components is that it appears to be an excellent storm-oriented coordinate system. This is especially true at the 48-h and 72-h forecast periods. A track extrapolated from warning and 12-h old positions is very representative of storm movement for the early (12- to 24-h) forecast periods, but not so of the later (48- to 72-h) forecast periods. Compared to simple extrapolation, the inclusion of climatology in the method described above provides a better CT/AT frame of reference at all forecast periods because it is evidently more representative of the true storm track at all time periods.

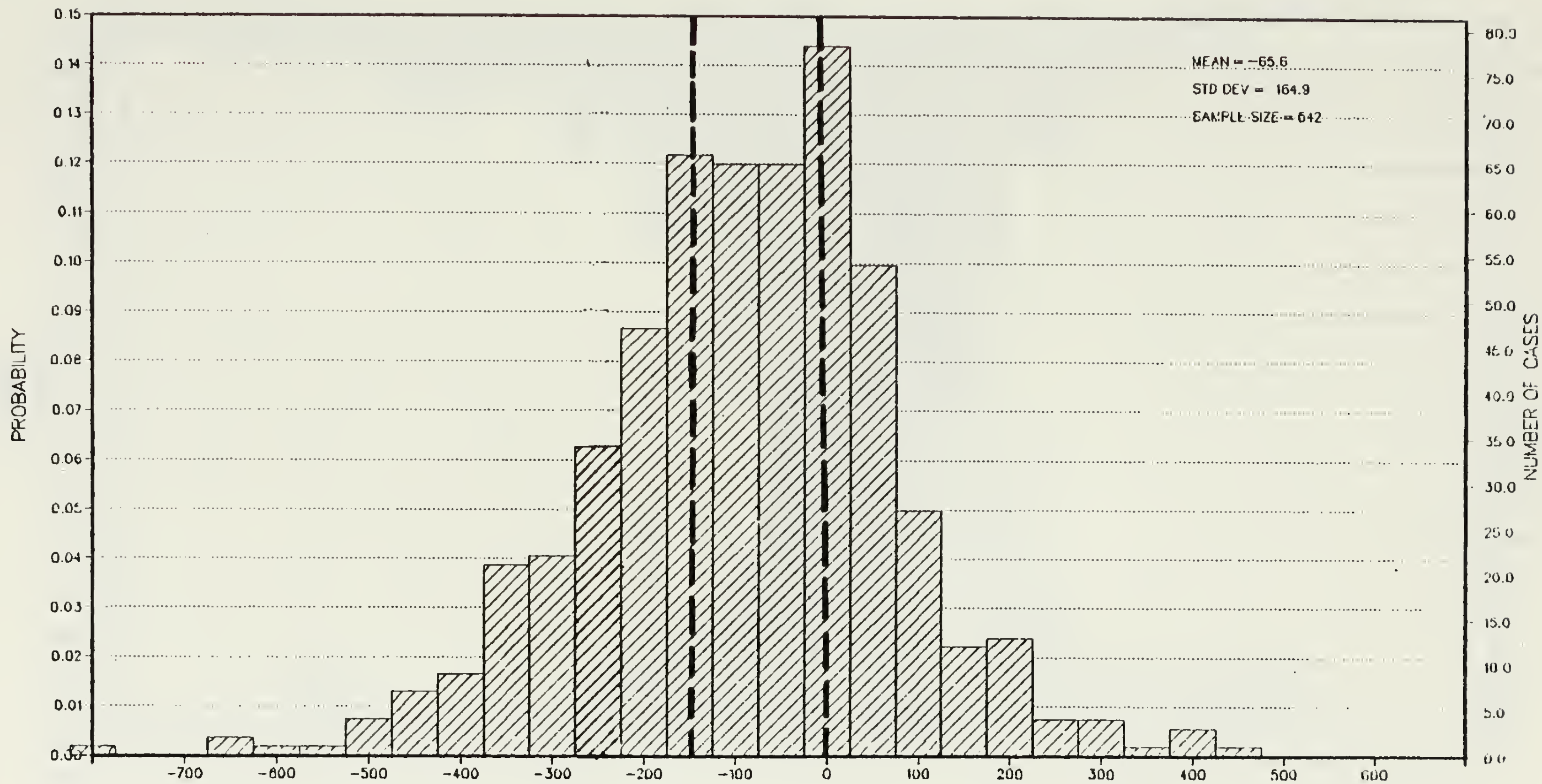


Figure 5a. Distribution of best-track 24-h along-track (AT) error components (km). Each point on abscissa indicates lowest value of the respective histogram cell. Dashes indicate approximate locations of tercile cutpoints.

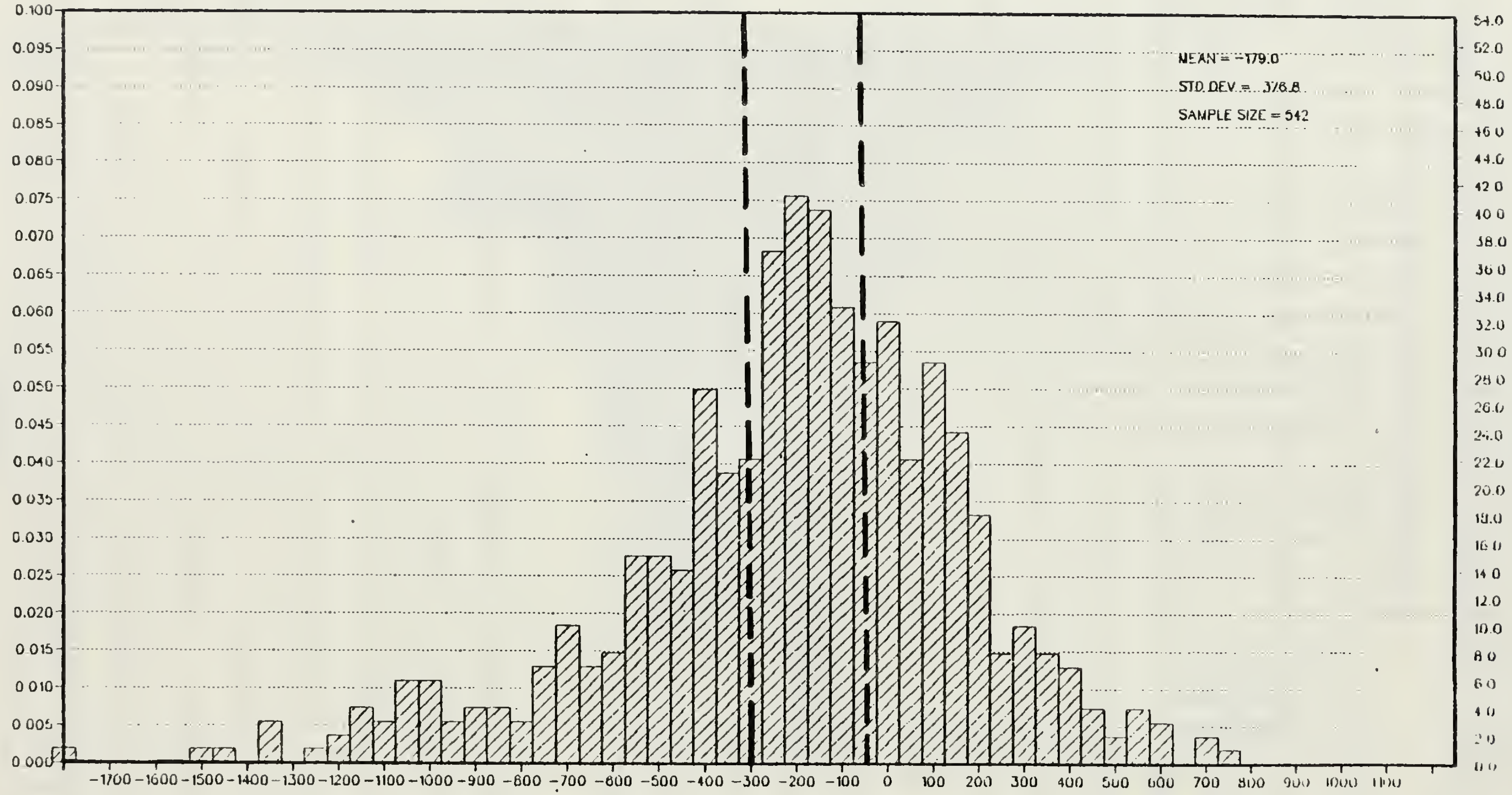


Figure 5b. Similar to Fig. 5a except for 48-h AT error components.

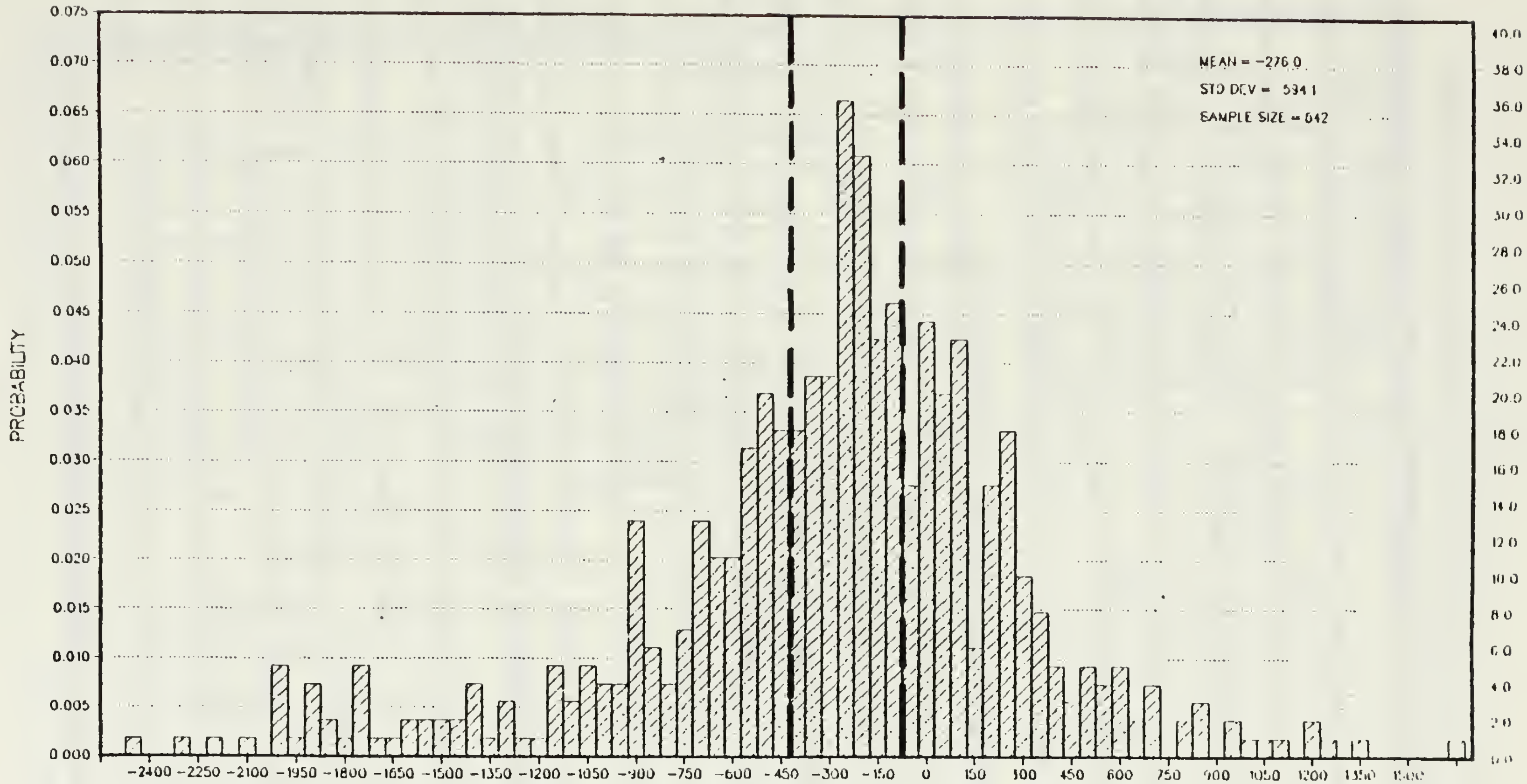


Figure 5c. Similar to Fig. 5a except for 72-h AT error components.

## D. CONTINGENCY TABLES, CLASS ERRORS AND M SCORES

After division of the best-track CT and AT components into terciles, a scoring system that assesses penalty points for forecasts that fall into the incorrect tercile is used to rank the NTCM. The NTCM forecasts are also divided into terciles and each forecast compared to the tercile for the best track. A forecast is defined as having a zero-class error if it falls into the same tercile as the best track, a one-class error if it is in a tercile adjacent to that of the best track and a two-class error if it is two terciles away from the best track. Contingency tables for the CT and AT components are then formed at each of the forecast intervals (24, 48 and 72 h) as shown in Tables 2a and 2b.

The upper portion of Table 2a gives the contingency tables for the NTCM for all three time periods. The cutpoints that define the tercile boundaries (see also Figs. 4a-c) are indicated just below the contingency tables. The zero-class errors are arranged in the bins located along the upper-left to lower-right diagonal. The two-class errors are located in the upper-right and lower-left bins and the remaining bins contain the one-class errors. A higher number in the zero-class diagonal relative to the one- and two-class error bins indicates a greater skill level. For example, the total number of zero-class CT errors for the 48-h time period is 280, or slightly more "hits" than at either 24 h (236) or 72 h (265). The totals column on the right side of each contingency table indicates the number in each best-track tercile (L, C and R). Similarly, the totals along the bottom row of each contingency table show the number of NTCM forecasts that fall into the best-track L, C and R categories. Notice that fewer NTCM forecasts fall into the "R" category at 48 and 72 h (123 and 130) than the best-track (178 and 189), but the number of NTCM forecasts in the "R" category at 24 h (171) is very close to the best track (186). This indicates the NTCM has a left bias in the later forecast periods, but none at the 24-h period.

TABLE 2a

Cross-track contingency tables, percentage of class error summaries and M scores

**24 h**

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 76 | 66 | 35 | 177 |
| C | 49 | 77 | 53 | 179 |
| R | 29 | 74 | 83 | 186 |
| Totals | 154 | 217 | 171 | 236 |

Cut Points: L < -75 km;
C = -75 to 50 km;
R ≥ 50 km

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 42.9 | 37.3 | 19.7 |
| C | 43.0 | 57.0 | ---- |
| R | 44.6 | 39.8 | 15.6 |
| Totals | 43.5 | 44.7 | 11.8 |

M Score = 68.3

**48 h**

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 113 | 56 | 19 | 188 |
| C | 51 | 94 | 31 | 176 |
| R | 33 | 72 | 73 | 178 |
| Totals | 197 | 222 | 123 | 280 |

Cut Points: L < -125 km;
C = -125 to 125 km;
R ≥ 125 km

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 60.1 | 29.8 | 10.1 |
| C | 53.4 | 46.6 | ---- |
| R | 41.0 | 40.5 | 18.5 |
| Totals | 51.6 | 38.9 | 9.5 |

M Score = 58.0

**72 h**

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 103 | 58 | 19 | 180 |
| C | 56 | 84 | 33 | 173 |
| R | 43 | 68 | 78 | 189 |
| Totals | 202 | 210 | 130 | 265 |

Cut Points: L < -200 km;
C = -200 to 200 km;
R ≥ 200 km

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 57.2 | 33.2 | 10.6 |
| C | 48.6 | 51.4 | ---- |
| R | 41.3 | 36.0 | 22.7 |
| Totals | 48.9 | 39.9 | 11.2 |

M Score = 62.1

TABLE 2b

Same as 2a, except for along-track.

### 24 h

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 120 | 41 | 14 | 175 |
| C | 93 | 69 | 25 | 187 |
| F | 68 | 61 | 51 | 180 |
| Totals | 281 | 171 | 90 | 240 |

Cut Points: S < -125 km; C = -125 to 15 km; F ≥ 15 km

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 68.6 | 23.4 | 8.0 |
| C | 36.9 | 63.1 | ---- |
| F | 28.3 | 33.9 | 37.8 |
| Totals | 44.3 | 40.1 | 15.3 |

M Score = 70.7

### 48 h

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 116 | 51 | 11 | 178 |
| C | 66 | 73 | 41 | 180 |
| F | 49 | 56 | 79 | 184 |
| Totals | 231 | 180 | 131 | 268 |

Cut Points: S < -275 km; C = -275 to -25 km; F ≥ -25 km

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 65.2 | 28.1 | 6.2 |
| C | 40.6 | 59.4 | ---- |
| F | 42.9 | 30.4 | 26.6 |
| Totals | 49.5 | 39.5 | 10.9 |

M Score = 61.4

### 72 h

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 111 | 59 | 13 | 183 |
| C | 45 | 87 | 45 | 177 |
| F | 46 | 48 | 88 | 182 |
| Totals | 202 | 194 | 146 | 286 |

Cut Points: S < -400 km; C = -400 to -50 km; F ≥ -50 km

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 60.7 | 32.2 | 7.1 |
| C | 49.2 | 50.8 | ---- |
| F | 48.4 | 26.4 | 25.3 |
| Totals | 52.8 | 36.5 | 10.8 |

M Score = 58.1

The lower half of Table 2a contains the percentages of NTCM zero-, one- and two-class errors for each (L,C,R) best-track tercile and the totals. The percentages provide information about the general distribution of errors. For example, notice that at 72 h, a higher percentage of two-class errors occur when the best track is in the "R" tercile (22.7) than in the "L" tercile (10.6). This indicates that at 72 h, the NTCM is more than twice as likely to be left of the best track when there is a two-class error.

Table 2b is similar to 2a, but contains the AT contingency tables (S, C, and F categories). The highest number of zero-class errors is in the 72-h period (286). Notice that the number of NTCM forecasts that fell into the slow (S) categories for all three time periods is very high. This agrees with the observation by Sandgathe (1985) that the NTCM movement is on the average 40% less than the observed cyclone movement.

A primary motivation for the tercile pattern separation into contingency tables is to determine if the NTCM correctly distinguishes between left-turning and right-turning as well as slow and fast storms (Elsberry and Peak, 1986). The lower portions of Tables 2a and 2b summarize the percentage of class errors for each category (L, C and R or S, C and F) of the sample. For example, in the 72-h portion of Table 2a, 180 of the storms moved to the left of the CLIPER track (total of first row). Of these, 103 (57.2%) are forecast correctly by the NTCM, 58 (33.2%) are forecast to be in the center tercile (one-class error) and 19 (10.6%) in the right-turning tercile (two-class error). The percent of each class of errors for the best-track terciles (L, C, R or S, C, F) and the total sample are tabulated below the contingency tables. In the above example for 72 h, the "totals" row shows that the 48.9% , 39.9% and 11.2% of the NTCM forecasts for CT were in the zero-, one- and two-class error categories, respectively. For comparison purposes, a purely random selection would have percentages of 33.3%, 44.4% and 22.2%, respectively. Thus, the NTCM is more skillful than a random forecast for this sample.

A further distillation of the information contained in the contingency tables is made as an aid to compare quantitatively the performance of forecasts. Preisendorfer and Mobley (1982) devised a scoring system to represent the level of skill in a forecast as a single number (M) defined as

$$M = V + 2W, \quad (1)$$

where (U,V,W) are the percentages of (zero-, one-, two-class) errors such that

$$U + V + W = 100. \quad (2)$$

The quantity M is simply a linear penalty score according to the error class; the lower the M score, the higher the degree of skill. In the example used above (Table 2a), the M score for the NTCM at 72 h for the CT component is 62.1. A random tercile selection would have an M score of 88.9. Therefore, the M score also indicates that the NTCM is more skillful than a random forecast.

An M score for the CLIPER is suggested as another standard of comparison. Because the terciles are defined relative to CLIPER, the CLIPER forecast track will always be in the center tercile. Thus, there can never be more than a one-class error. However, the terciles are constructed so that for both the CT and the AT distributions 66.7% of the cases are not in the center tercile. The CLIPER forecast will always fail by one class in these cases. Thus, the M score is simply 66.7 for both the CT and the AT components. For the total sample (see Tables 2a and 2b), the CT/AT M scores for the NTCM at 48 h (58.0/61.4) and 72 h (62.1/58.1) indicate that the NTCM is more skillful than CLIPER at the later forecast periods. However, the 24-h CT/AT M scores (68.3/70.7) indicate that the NTCM is essentially a no-skill forecast at this time period.

# V. RESULTS

## A. TOTAL SAMPLE STATISTICS

The CT and AT percentages of class errors, M scores, mean and median errors and systematic errors for the total NTCM sample are summarized in Table 3. The CT M scores (68.3, 58.0 and 62.1 at 24, 48 and 72 h) suggest that overall, the NTCM forecasts are more skillful at 48 and 72 h than at 24 h. The AT M scores (70.7, 61.4 and 58.1 at 24, 48 and 72 h) also indicate a similar result. Also, the NTCM performs better than the CLIPER (M=66.7) at these time periods. However, the 24-h M scores of the CT and AT

TABLE 3

NTCM total sample (542 cases) percent class errors and M scores (left). Systematic, mean and median forecast errors (right).

| | | %0 | %1 | %2 | M |
|---|---|---|---|---|---|
| 24 h | CT | 43.5 | 44.7 | 11.8 | 68.3 |
| | AT | 44.3 | 40.6 | 15.1 | 70.8 |
| 48 h | CT | 51.7 | 38.7 | 9.6 | 57.9 |
| | AT | 49.4 | 39.5 | 11.1 | 61.7 |
| 72 h | CT | 48.9 | 39.7 | 11.4 | 62.5 |
| | AT | 52.8 | 36.3 | 10.9 | 58.1 |

| | $\Sigma X$ | $\Sigma Y$ | Mn | Md |
|---|---|---|---|---|
| 12 h | 47 | 2 | 137 | 127 |
| 24 h | 60 | -2 | 225 | 194 |
| 36 h | 45 | 4 | 301 | 263 |
| 48 h | 17 | -16 | 397 | 355 |
| 60 h | 9 | -3 | 508 | 453 |
| 72 h | -7 | -9 | 626 | 565 |

components (68.3 and 70.8) indicate that the NTCM represents the storm movement no better than CLIPER. Notice that the relatively high percentage of AT two-class errors at 24 h (15.1%). Referring back to the contingency table (Table 2b) for this forecast period, it can be seen that this high percentage is due to a large number of two-class errors in the lower-left corner of the table (68). This indicates that the NTCM has a slow bias, especially at the 24-h period.

The mean (Mn) and median (Md) forecast errors for the overall sample of NTCM forecasts (Table 3) and the CLIPER (Table 4) suggest that the NTCM performance is generally no better than CLIPER at the early (12- and 24-h) time periods. However, the NTCM consistently has lower forecast errors at the later (36-through 72-h) periods. For this sample of forecasts, the CT/AT error statistics, which measure forecasting skill based on "storm-motion" coordinates, are in good agreement with the forecast error statistics, which account only for the distance between the forecast and the best-track position.

TABLE 4

CLIPER systematic ($\Sigma X$ and $\Sigma Y$), mean (Mn) and median (Md) forecast errors (km) for the total sample (542 cases).

| | $\Sigma X$ | $\Sigma Y$ | Mn | Md |
|---|---|---|---|---|
| 12 h | -6 | 21 | 107 | 90 |
| 24 h | 3 | 47 | 206 | 172 |
| 36 h | 22 | 73 | 329 | 278 |
| 48 h | 41 | 96 | 457 | 373 |
| 60 h | 48 | 115 | 592 | 480 |
| 72 h | 56 | 121 | 730 | 590 |

The slow bias of the NTCM is also evident in the zonal ($\Sigma X$) and meridional ($\Sigma Y$) errors (Table 3). The 12-, 24- and 36-h $\Sigma X$ averages are 47, 60 and 45 km, which indicates that the NTCM is initially east of the best-track position. For westward-moving storms, these positive values suggest that the NTCM is "slow" during the early forecast periods. Most of the storms in this sample will have a component toward the west because of the requirement that a complete 72-h track be included. This will tend to reduce the number of the eastward-moving storms that tend to undergo extratropical transition prior to 72 h. Notice that in the 48- to 72-h time period, the values of $\sum X$ decrease from 17 to -7, which indicates that the average NTCM position becomes slightly west of the best-track position at 72 h. However, this error is very small compared with the mean and median forecast errors. The meridional ($\sum Y$) components of the systematic error of the NTCM are also negligible. In fact, the largest deviation from zero at 48 h is only 16 km south of best-track latitude (Table 3), which is well within the "noise".

The CLIPER systematic errors (Table 4) indicate that the average forecast positions are generally east and north of the best track. although these systematic errors are not large, near zero values had been expected. This seems to suggest that this sample from 1981-3 had somewhat different characteristics than the sample used to create the CLIPER algorithm.

## B. LATITUDE EFFECTS

As indicated in Fig. 1a, the sample of NTCM forecasts is divided into southern (latitudes < 13° N), central (between 13° and 17° N) and northern ( > 17° N) samples. The locations of the latitude and longitude (section C) tercile cutpoints are shown in Fig. 6.

Two obvious points arise from an inspection of the M scores of the latitude-stratified subsample (Table 5). First, the M scores of the 48- and 72-h CT components for the southern area are much lower than those for the central and northern areas. This suggest that the NTCM is more skillful in forecasting the direction of storm movement for systems with initial positions south of 13° N. Second, both CT and AT M scores indicate that the NTCM has less skill in forecasting direction and speed at 24 h than at 48 h and 72 h for all

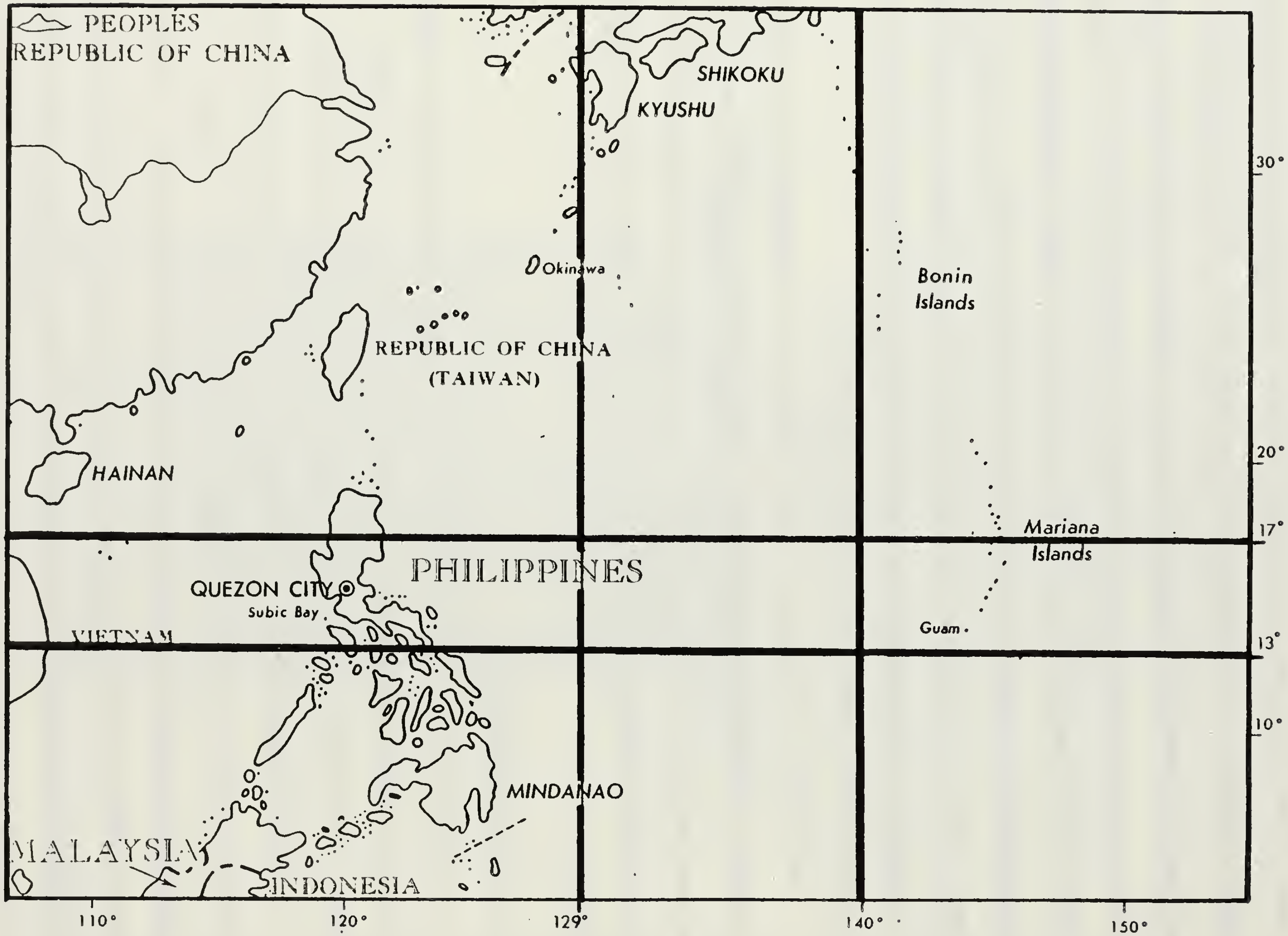


Figure 6. Locations of latitude and longitude tercile cutpoints in the western North Pacific (thick lines).

TABLE 5

Cross-track and along-track percent class errors and M scores
for NTCM forecasts stratified by latitude.

| | Latitude < 13° N | | | | Latitude 13° to 17° | | | | Latitude ≥ 17° | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | %0 | %1 | %2 | M | %0 | %1 | %2 | M | %0 | %1 | %2 | M |
| 24 h CT | 47.5 | 41.0 | 11.5 | 64.0 | 42.4 | 44.6 | 13.0 | 70.6 | 40.7 | 48.3 | 11.0 | 70.3 |
| 24 h AT | 44.3 | 36.0 | 19.7 | 75.4 | 37.3 | 44.1 | 18.6 | 81.3 | 51.1 | 41.8 | 7.1 | 56.0 |
| 48 h CT | 57.9 | 34.3 | 8.8 | 50.8 | 53.7 | 37.3 | 9.0 | 55.3 | 43.4 | 45.6 | 11.0 | 70.3 |
| 48 h AT | 53.0 | 33.3 | 10.9 | 57.9 | 44.6 | 39.0 | 16.4 | 71.8 | 50.6 | 43.4 | 6.0 | 55.4 |
| 72 h CT | 55.7 | 38.3 | 6.0 | 50.3 | 51.4 | 35.6 | 13.0 | 61.6 | 39.6 | 45.0 | 15.4 | 75.8 |
| 72 h AT | 54.1 | 36.1 | 9.8 | 55.7 | 53.1 | 33.3 | 13.6 | 60.5 | 51.0 | 39.6 | 9.3 | 58.2 |
| | No. in Subsample = 183 | | | | No. in Subsample = 177 | | | | No. in Subsample = 182 | | | |

TABLE 6

Mean (Mn), median (Md), and systematic errors (km)
for NTCM forecasts stratified by latitude.

| | Latitude < 13° N | | | | Latitude 13° to 17° N | | | | Latitude ≥ 17° N | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\Sigma X$ | $\Sigma Y$ | Mn | Md | $\Sigma X$ | $\Sigma Y$ | Mn | Md | $\Sigma X$ | $\Sigma Y$ | Mn | Md |
| 12 h | 45 | 5 | 158 | 148 | 62 | 2 | 137 | 124 | 33 | -1 | 116 | 106 |
| 24 h | 76 | 23 | 261 | 235 | 109 | -10 | 228 | 198 | -4 | -19 | 188 | 165 |
| 36 h | 58 | 14 | 341 | 301 | 119 | 3 | 298 | 263 | -38 | -5 | 264 | 246 |
| 48 h | 14 | -23 | 433 | 368 | 135 | -17 | 392 | 345 | -94 | -9 | 366 | 346 |
| 60 h | 2 | -16 | 527 | 457 | 164 | -4 | 507 | 462 | -136 | 12 | 489 | 441 |
| 72 h | -6 | -21 | 617 | 543 | 200 | -3 | 616 | 580 | -210 | -4 | 644 | 578 |

No. in Subsample = 183 | No. in Subsample = 177 | No. in Subsample = 182

TABLE 7

Mean (Mn), median (Md), and systematic errors (km)
for CLIPER forecasts stratified by latitude.

| | Latitude < 13° N | | | | Latitude 13° to 17° N | | | | Latitude ≥ 17° N | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ΣX | ΣY | Mn | Md | ΣX | ΣY | Mn | Md | ΣX | ΣY | Mn | Md |
| 12 h | -4 | 15 | 119 | 101 | -10 | 20 | 96 | 88 | -4 | 29 | 104 | 80 |
| 24 h | 16 | 29 | 233 | 195 | -2 | 49 | 192 | 161 | -6 | 63 | 193 | 162 |
| 36 h | 46 | 31 | 382 | 302 | 24 | 84 | 309 | 269 | -4 | 103 | 295 | 264 |
| 48 h | 59 | 41 | 539 | 415 | 67 | 117 | 432 | 376 | -3 | 132 | 400 | 342 |
| 60 h | 48 | 61 | 694 | 525 | 117 | 149 | 566 | 496 | -20 | 136 | 514 | 439 |
| 72 h | 43 | 86 | 841 | 619 | 185 | 178 | 714 | 606 | -57 | 102 | 633 | 537 |
| | No. in Subsample = 183 | | | | No. in Subsample = 177 | | | | No. in Subsample = 182 | | | |

three subsamples. This result can also be seen in the forecast error statistics (Table 6), which indicate that the NTCM has higher mean and median 24-h forecast errors in the southern and central areas than CLIPER (Table 7).

Although the CT and AT M scores generally decrease with increasing forecast period, the AT M scores for the northern subsample are an exception. The 24-h score is very low (56.0) with respect to that for the total sample (70.8), and the M score increases slightly to 58.2 at 72 h. This seems to indicate that the slow bias of the NTCM (mentioned above) is less pronounced for storms with initial latitudes north of 17°N. Inspection of the contingency table (Table A-4, appendix) indicates that the number of two-class errors in the slow category for the northern subsample (11) is much less than those for the southern (28) and central (29) subsamples. In addition, the NTCM median 24 h forecast error (Table 6) for the northern area is much smaller than those for the southern and central areas (165 km versus 235 and 198 km, respectively). This 24-h median forecast error is even slightly smaller than that of CLIPER (175 km, see Table 4) for the total sample. Therefore, the slow bias of the NTCM at 24 h is largely due to the storms initially south of 17° N. This initial slow bias probably contributes to increased forecast errors at 48 and 72 h because it leads to an incorrect timing of recurvature (Sandgathe, 1985). Missing the time of recurvature can produce large forecast errors. Although the AT errors for the northern area are quite small, the large CT errors seem to offset them at the 48 and 72 h time periods.

Notice that the NTCM mean and median forecast errors at 72 h (Table 6) for the northern subsample (644 and 578 km) are greater than those of the CLIPER (Table 7) for this subsample (633 and 537 km), which is consistent with the NTCM CT M score at 72 h (75.3) being much higher than that of the CLIPER (66.7). Therefore, the NTCM is no more skillful than CLIPER for storms north of 17° N, even at the 48- and 72-h periods. Only in the southern subsample does the NTCM clearly outperform CLIPER at 48 and

72 h with respect to all of the error statistics; CT, AT and mean and median forecast errors (see Tables 6 and 7).

One explanation of the apparently good performance for NTCM in terms of the CT errors (especially at 48 and 72 h) in the southern area may be that the synoptic features that cause recurvature are less likely to extend into this region (south of 13° N). Therefore, the lack of recurvature influences on the storm tracks probably contribute to the low CT M scores at 72 h (50.3 for the southern area versus 61.6 and 75.8 for the central and northern areas).

The systematic errors of the NTCM (Table 6) indicate that the meridional ($\sum Y$) averages for all three areas are very close to zero and show no systematic change with increasing forecast period. However, the central area exhibits an increase in zonal ($\sum X$) error from 62 km to 200 km from 12 to 72 h, which indicates that the NTCM forecasts are east of the best track. Conversely, the northern area zonal error decreases from 33 km to -210 km throughout the period, with the NTCM becoming farther west of the best track. The absence of such large systematic errors in the southern area is consistent with the other error statistics, which suggests that the NTCM performs best for storms initially south of 13° N.

## C. LONGITUDE EFFECTS

The cutpoints for dividing the sample of forecasts into western, middle and eastern areas are 129° E and 140° E (Figs. 1b Fig. 6). The lowest CT M scores for the NTCM are found in the western area (Table 8). This is due to a low percentage of two-class errors in the western area for all three time periods (3.5, 2.4 and 5.3% for 24, 48 and 72 h). The contingency tables (Tables A-7, A-8 and A-9) also do not indicate any left or right bias of the NTCM in the western area. Although the CT M scores at 24 and 48 h are very low (50.8 and 43.8) for the western area, the corresponding AT M scores are higher

TABLE 8

Cross-track and along-track percent class errors and M scores for NTCM forecasts stratified by longitude.

| | Longitude < 129° E | | | | Longitude 129° to 140° E | | | | Longitude ≥ 140° E | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | %0 | %1 | %2 | M | %0 | %1 | %2 | M | %0 | %1 | %2 | M |
| 24 h CT | 52.7 | 43.8 | 3.5 | 50.8 | 36.6 | 49.4 | 14.0 | 77.4 | 42.3 | 40.6 | 17.1 | 74.8 |
| 24 h AT | 36.7 | 49.7 | 13.6 | 76.9 | 44.6 | 40.9 | 14.5 | 69.9 | 50.8 | 32.1 | 17.1 | 66.3 |
| 48 h CT | 58.6 | 39.0 | 2.4 | 43.8 | 46.2 | 40.3 | 13.4 | 67.1 | 50.8 | 36.9 | 12.3 | 61.5 |
| 48 h AT | 47.3 | 37.9 | 14.8 | 67.4 | 47.8 | 44.1 | 8.0 | 60.1 | 52.9 | 36.4 | 10.7 | 57.8 |
| 72 h CT | 47.3 | 47.3 | 5.3 | 57.9 | 41.4 | 42.5 | 16.1 | 74.7 | 57.8 | 29.9 | 12.3 | 54.5 |
| 72 h AT | 52.1 | 34.9 | 13.0 | 60.9 | 50.0 | 43.0 | 7.0 | 57.0 | 56.2 | 31.0 | 12.8 | 56.6 |
| | No. in Subsample = 169 | | | | No. in Subsample = 186 | | | | No. in Subsample = 187 | | | |

TABLE 9

Mean (Mn), median (Md), and systematic errors (km)
for NTCM forecasts stratified by longitude.

| | Longitude < 129° E | | | | Longitude 129° to 140° E | | | | Longitude ≥ 140° E | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ΣX | ΣY | Mn | Md | ΣX | ΣY | Mn | Md | ΣX | ΣY | Mn | Md |
| 12 h | 25 | -6 | 126 | 120 | 58 | -16 | 133 | 122 | 55 | 27 | 151 | 134 |
| 24 h | 45 | -16 | 194 | 173 | 61 | -40 | 231 | 224 | 72 | 49 | 248 | 198 |
| 36 h | 50 | -19 | 251 | 232 | 29 | -28 | 305 | 292 | 58 | 56 | 341 | 273 |
| 48 h | 24 | -60 | 348 | 322 | -9 | -42 | 400 | 367 | 37 | 48 | 439 | 368 |
| 60 h | 3 | -40 | 449 | 417 | -33 | -34 | 516 | 486 | 55 | 62 | 553 | 481 |
| 72 h | 1 | -49 | 562 | 520 | -74 | -41 | 637 | 582 | 52 | 57 | 673 | 574 |
| | No. in Subsample = 169 | | | | No. in Subsample = 186 | | | | No. in Subsample = 187 | | | |

Table 10

Mean (Mn), median (Md), and systematic errors (km) for CLIPER forecasts stratified by longitude.

| | Longitude < 129° E | | | | Longitude 129° to 140° E | | | | Longitude ≥ 140° E | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ΣX | ΣY | Mn | Md | ΣX | ΣY | Mn | Md | ΣX | ΣY | Mn | Md |
| 12 h | -26 | 19 | 96 | 84 | -8 | 10 | 98 | 79 | 15 | 35 | 124 | 108 |
| 24 h | -28 | 32 | 183 | 152 | -10 | 27 | 191 | 158 | 43 | 80 | 242 | 212 |
| 36 h | -17 | 45 | 302 | 246 | -8 | 49 | 297 | 262 | 88 | 121 | 385 | 324 |
| 48 h | -1 | 60 | 441 | 362 | -8 | 66 | 408 | 353 | 127 | 160 | 522 | 446 |
| 60 h | 11 | 71 | 593 | 465 | -18 | 73 | 523 | 452 | 147 | 198 | 659 | 581 |
| 72 h | 28 | 73 | 746 | 579 | -39 | 65 | 650 | 552 | 175 | 222 | 794 | 705 |
| | No. in Subsample = 169 | | | | No. in Subsample = 186 | | | | No. in Subsample =187 | | | |

(76.9 and 67.4) than those in the middle and eastern areas. This offsetting effect degrades the overall performance of the NTCM. Research is required to improve the NTCM so that it has low M scores in both components.

The eastern area has the next lowest CT M scores, which decrease from 74.8 to 61.5 to 54.5 at 24, 48 and 72 h. The 72-h value is even slightly lower than the corresponding western area CT M score. The highest CT M scores are found in the middle area (77.4, 67.1 and 74.7 at 24, 48 and 72 h). The CT performance for this longitude band is less skillful than CLIPER (M = 66.7) at all forecast periods.

Except for the very poor AT performance in the western area mentioned above, the AT M scores do not show major variations between longitude bands. The AT M scores at all three time periods for the middle and eastern areas are similar to the those of the total NTCM sample (Table 3).

The systematic error measures of the NTCM (Table 9) also show no major departures from those of the overall sample statistics in Table 3. The $\sum X$ and $\sum Y$ for all three subsamples are generally less than 70 km. In the eastern area the NTCM has small and nearly constant eastward zonal ($\sum X \approx 50$ km) and northward meridional ($\sum Y \approx 50$ km) errors throughout the forecast period. In the middle area, the errors are fairly constant throughout the forecast period with a slight southward meridional displacement ($\sum Y \approx -30$ km) and a monotonic variation from an eastward ($\sum X = 58$ km) to a westward zonal displacement ($\sum X = -74$ km). For a westward-moving storm, this may be interpreted as the NTCM track starting out "slow" or east of the best track and "passing" or moving west of the best-track longitude over the 72-h time period. Very small variations of the systematic errors with forecast period (< 50 km) are observed in the western area. This is consistent with the earlier finding that the CT/AT M scores are generally lower and indicates again that the NTCM is highly skillful in the western area.

The mean and median forecast errors (Table 9) are also consistent with the CT/AT and systematic error statistics. That is, the smallest mean and median forecast errors for all forecast periods are found in the western area and the highest are in the eastern area. Although the NTCM is nearly as skillful as the CLIPER at 24 h in the eastern area, the CLIPER generally outperforms the NTCM at 12 and 24 h. In addition, the CLIPER forecast errors are almost as low or lower than the NTCM at all forecast periods in the middle area. The NTCM outperforms CLIPER by about 40 to 100 km (both mean and median errors) at 36 through 72 h in the western and eastern areas. In the western area, the 48- and 72-h NTCM median forecast errors are 93 and 184 km lower than those of the CLIPER.

In summary, the NTCM performs better in terms of all of the error statistics for storms with initial longitudes west of 129° E. One explanation may be that the western area storms are closer to the relatively data-rich continental areas (Fig. 6) compared to the data-sparse eastern regions. Thus, the initial wind fields in the NTCM are more likely to be representative of the true wind fields. The frequency of storm fix positions also increases in this area because of the proximity to land-based radar and synoptic data, which provides a better initial position for the NTCM.

## D. INTENSITY EFFECTS

As indicated in Fig. 1c, the sample of NTCM forecasts is divided into storms with initial intensity $< 50$ kt, between 50 and 75 kt and $\geq 80$ kt. These groups will be referred to as the weak, moderate and intense subsamples, respectively. Recall that the initial intensity of the bogus storm in the NTCM is always 60 kt, which is near the mean of the moderate subsample.

The M scores for both CT and AT errors are relatively low for the moderate subsample (Table 11). In fact, the M scores for both CT and AT at every forecast period (24, 48 and 72 h) are considerably smaller for the moderate subsample than those for the other two

TABLE 11

Cross-track and along-track percent class errors and M scores for NTCM forecasts stratified by intensity.

| | Intensity ≤ 45 knots | | | | Intensity 50 to 75 knots | | | | Intensity ≥ 80 knots | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | %0 | %1 | %2 | M | %0 | %1 | %2 | M | %0 | %1 | %2 | M |
| 24 h CT | 40.7 | 41.7 | 17.6 | 76.9 | 48.9 | 41.8 | 8.3 | 58.4 | 41.0 | 49.4 | 9.6 | 68.6 |
| 24 h AT | 39.6 | 37.3 | 23.1 | 83.5 | 49.5 | 38.4 | 12.1 | 62.6 | 43.8 | 46.1 | 10.1 | 66.3 |
| 48 h CT | 46.7 | 40.1 | 13.2 | 66.5 | 61.0 | 33.0 | 6.0 | 45.0 | 47.2 | 43.2 | 9.6 | 62.4 |
| 48 h AT | 44.0 | 41.2 | 14.8 | 70.8 | 58.8 | 31.9 | 9.3 | 50.5 | 45.5 | 45.5 | 9.0 | 63.5 |
| 72 h CT | 48.9 | 40.1 | 11.0 | 62.1 | 56.6 | 36.8 | 6.6 | 50.0 | 41.0 | 42.1 | 16.9 | 75.9 |
| 72 h AT | 50.5 | 35.7 | 13.8 | 63.3 | 56.6 | 33.0 | 10.4 | 53.8 | 51.1 | 40.5 | 8.4 | 57.3 |
| | No. in Subsample = 182 | | | | No. in Subsample = 182 | | | | No. in Subsample = 178 | | | |

TABLE 12

Mean (Mn), median (Md), and systematic errors (km) for NTCM forecasts stratified by intensity.

| | Intensity ≤ 45 knots | | | | Intensity 50 to 75 knots | | | | Intensity ≥ 80 knots | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ΣX | ΣY | Mn | Md | ΣX | ΣY | Mn | Md | ΣX | ΣY | Mn | Md |
| 12 h | 73 | 13 | 173 | 158 | 50 | 1 | 125 | 120 | 16 | -8 | 112 | 100 |
| 24 h | 108 | 4 | 275 | 240 | 73 | -2 | 213 | 194 | -3 | -8 | 187 | 162 |
| 36 h | 94 | 15 | 358 | 289 | 61 | -9 | 282 | 277 | -20 | 6 | 261 | 234 |
| 48 h | 69 | -18 | 461 | 369 | 54 | -44 | 374 | 356 | -73 | 13 | 356 | 323 |
| 60 h | 84 | -25 | 566 | 491 | 44 | -37 | 480 | 448 | -105 | 55 | 477 | 417 |
| 72 h | 82 | -37 | 671 | 591 | 43 | -32 | 592 | 557 | -150 | 41 | 614 | 558 |
| | No. in Subsample = 182 | | | | No. in Subsample = 182 | | | | No. in Subsample = 178 | | | |

TABLE 13

Mean (Mn), median (Md), and systematic errors (km) for CLIPER forecasts stratified by intensity.

| | Intensity ≤ 45 knots | | | | Intensity 50 to 75 knots | | | | Intensity ≥ 80 knots | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ΣX | ΣY | Mn | Md | ΣX | ΣY | Mn | Md | ΣX | ΣY | Mn | Md |
| 12 h | -15 | 21 | 134 | 111 | 7 | 23 | 103 | 84 | -10 | 20 | 81 | 73 |
| 24 h | -15 | 48 | 234 | 210 | 31 | 38 | 215 | 166 | -9 | 54 | 168 | 155 |
| 36 h | -9 | 60 | 346 | 291 | 71 | 55 | 361 | 281 | 5 | 103 | 279 | 254 |
| 48 h | -9 | 68 | 461 | 389 | 107 | 71 | 517 | 389 | 24 | 152 | 393 | 350 |
| 60 h | -31 | 76 | 574 | 483 | 134 | 84 | 680 | 534 | 40 | 187 | 520 | 455 |
| 72 h | -34 | 83 | 694 | 575 | 157 | 89 | 835 | 652 | 44 | 194 | 660 | 552 |
| | No. in Subsample = 182 | | | | No. in Subsample = 182 | | | | No. in Subsample = 178 | | | |

subsamples. Nearly all of the M scores in the moderate subsample are at least ten points better than the M scores from the total sample (Table 3). An exception is the 72-h AT M score, which is 53.8 for the moderate subsample and 58.1 for the total sample. The M scores of the weak subsample are generally the highest of the three subsamples. A possible explanation is that the deep tropospheric bogus storm in the NTCM is not a good representation of these weak storms. The M scores for the intense subsample are closer to the total sample scores (Table 3), but higher than the 48- and 72-h CT cases.

The contingency tables for intensity stratifications (Tables A-13 to A-18) provide further explanation of the M scores. Notice that for all three forecast periods, the NTCM CT errors are biased to the right of the best track for the weak group, are fairly evenly distributed about the best track for the moderate subsample, and are typically to the left of the best track for the intense subsample. These results suggest that the NTCM may predict recurvature too quickly for the less intense storms and may be slow in recurving storms with intensity ≥ 80 kt. The 60-kt bogus storm may result in excessive poleward deflecting of the weak storms that are expected to be traveling from east to west. By contrast, the poleward deflection may be underestimated by the bogus storm in the NTCM when the storm is actually more intense. This is especially true for right-moving storms (relative to CLIPER) at 72 h, when the NTCM tends to forecast a left-moving path (two-class error) in 40.6% of the cases.

The AT M scores (Table 11) are also lower for the moderate subsample, although at 72 h, they are not much lower than that of the intense subsample (53.8 versus 57.3, respectively). The high percentage of two-class errors in the fast category of the 24-, 48- and 72-h AT contingency tables (Tables A-16, A-17 and A-18) indicate a slow bias in each subsample. For the weak subsample, a high percentage of two-class errors occurs at all the three forecast intervals, especialy at 24 h (50%). Although this slow bias is less prevalent in the intense subsample, the AT M scores are higher than those of the moderate group at each time interval. The lower M scores in the moderate subsample are due to the lower number of one-class errors, even though at 72 h there is a high percentage (31.1%) of two-class errors in which the NTCM is slower than the best track (Table A-18).

The systematic errors for the NTCM (Table 12) indicate that there is little or no systematic growth in longitudinal ($\sum X$) errors in the moderate and weak subsamples. The NTCM position in both cases is east (73 km and 50 km for the weak and moderate subsamples, respectively) of the average best-track position at 12 h and remains almost constant with increasing time. However, a large systematic growth in longitudinal error occurs in the intense subsample. The zonal error ($\sum X$) increases from 16 to -150 km monotonically with time, which indicates that the average NTCM position becomes farther west of the best track with increasing forecast period for those intense storms. Only a small meridional error ($\sum Y$) is found for the different storm intensities. The 72-h NTCM forecasts are slightly to the south of the best track for the weak and moderate subsamples and slightly to the north in the moderate subsample.

Forecast errors of the NTCM in the moderate subsample are much smaller than those of CLIPER beyond 12 h (Tables 12 and 13). The NTCM mean and median forecast errors in the intense subsample are about the same as in the moderate subsample, even though the CT and AT results seem to indicate much lower directional and speed errors for the moderate subsample. A possible explanation for this result is that the accuracy of the initial position from fixes by any platform (aircraft, satellite or radar) is much greater for cyclones that have developed an eye (or at least a well-defined circulation center). Since initial position errors are propagated along the forecast track, the NTCM mean and median forecast errors for the intense subsample should be smaller than those of the weak or moderate subsamples by virtue of better initial position inputs. The CLIPER (which should be unbiased with respect to storm-related parameters) mean and median forecast errors also decrease markedly from weak to intense subsamples (Table 13), which supports this argument. In addition, the CT and AT M scores indicate that the NTCM predicts the storm direction and speed much more accurately for moderate storms than for either weak or intense storms. Finally, the weak subsample has much larger mean and median forecast errors (as well as higher CT and AT M scores) than the other subsamples throughout the entire forecast period. Thus, the 60-kt specification of the NTCM storm bogus may be inappropriate for weak storms.

## E. PAST 12-HOUR INTENSITY CHANGE EFFECTS

The three subsamples of NTCM forecasts are classified as weakening (past 12-h intensity change, or "Δ intensity" ≤ 0 kt), intensifying (Δ intensity 5 and 10 kt) and rapidly intensifying (Δ intensity ≥ 15 kt). As indicated earlier, the number of forecasts (Table 14) is not equally distributed among the three categories due to the small range of possible Δ-intensity values.

The NTCM CT M scores are the lowest for the rapidly intensifying storms (Table 14) at all forecast periods, although the intensifying storms had CT M scores almost as low at 72 h. The AT M scores for the rapid intensifiers were much lower (more than 10 points at all three forecast periods) than those of the weakening storms. These results indicate that the NTCM forecasts direction and speed more accurately for storms that are intensifying (slowly or rapidly) than for weakening storms.

The NTCM mean and median forecast errors (Table 15) follow the same pattern as the CT and AT M scores. That is, the errors for the rapidly intensifying storms are much smaller than those of the weakening storms (more than 100 km smaller mean and median errors at 72 h). The trend of decreasing mean and median forecast errors from weakening to intensifying to rapidly intensifying subsamples holds for all forecast periods except between 12 and 36 h. For these periods, the median forecast errors increase slightly for the intensifying storms, and then decrease for the rapid intensifiers (Table 15).

TABLE 14

Cross-track and along-track percent class errors and M scores for NTCM forecasts stratified by past 12-h intensity change.

| | | Δ Intensity ≤ 0 knots | | | | Δ Intensity 5 to 10 knots | | | | Δ Intensity ≥ 15 knots | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | %0 | %1 | %2 | M | %0 | %1 | %2 | M | %0 | %1 | %2 | M |
| 24 h | CT | 46.3 | 41.6 | 12.1 | 65.8 | 42.0 | 42.0 | 16.0 | 74.0 | 43.4 | 51.5 | 5.1 | 61.7 |
| | AT | 39.5 | 40.5 | 20.0 | 80.5 | 49.1 | 37.3 | 13.6 | 64.5 | 42.4 | 46.5 | 11.1 | 68.7 |
| 48 h | CT | 50.5 | 39.5 | 10.0 | 59.5 | 51.5 | 38.5 | 10.0 | 58.5 | 55.6 | 37.4 | 7.1 | 51.6 |
| | AT | 44.7 | 40.0 | 15.3 | 70.6 | 52.7 | 37.3 | 10.0 | 57.3 | 53.5 | 40.4 | 6.1 | 52.6 |
| 72 h | CT | 44.2 | 42.1 | 13.7 | 69.5 | 53.3 | 34.9 | 11.8 | 58.5 | 55.6 | 35.3 | 9.1 | 53.5 |
| | AT | 48.4 | 36.3 | 15.3 | 66.9 | 54.4 | 37.9 | 7.7 | 53.3 | 56.6 | 35.3 | 8.1 | 51.5 |
| | | No. in Subsample = 190 | | | | No. in Subsample = 169 | | | | No. in Subsample = 99 | | | |

TABLE 15

Mean (Mn), median (Md), and systematic errors (km)
for NTCM forecasts stratified by past 12-h intensity change.

| | Δ Intensity ≤ 0 knots | | | | Δ Intensity 5 to 10 knots | | | | Δ Intensity ≥ 15 knots | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ΣX | ΣY | Mn | Md | ΣX | ΣY | Mn | Md | ΣX | ΣY | Mn | Md |
| 12 h | 34 | 4 | 138 | 121 | 43 | 3 | 146 | 130 | 61 | -6 | 114 | 106 |
| 24 h | 53 | 8 | 239 | 202 | 46 | -3 | 225 | 193 | 76 | -13 | 195 | 183 |
| 36 h | 49 | 14 | 313 | 266 | 21 | 0 | 303 | 277 | 62 | -7 | 267 | 239 |
| 48 h | 24 | -4 | 413 | 357 | -3 | -22 | 396 | 348 | 48 | -20 | 348 | 326 |
| 60 h | 19 | 11 | 535 | 510 | -34 | 8 | 503 | 439 | 38 | -3 | 448 | 379 |
| 72 h | 7 | -9 | 662 | 633 | -54 | 17 | 613 | 537 | 34 | 2 | 553 | 489 |
| | No. in Subsample = 190 | | | | No. in Subsample = 169 | | | | No. in Subsample = 99 | | | |

TABLE 16

Mean (Mn), median (Md), and systematic errors (km)
for CLIPER forecasts stratified by past 12-h intensity change.

| | Δ Intensity ≤ 0 knots | | | | Δ Intensity 5 to 10 knots | | | | Δ Intensity ≥ 15 knots | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ΣX | ΣY | Mn | Md | ΣX | ΣY | Mn | Md | ΣX | ΣY | Mn | Md |
| 12 h | 0 | 25 | 96 | 83 | -8 | 23 | 118 | 97 | -8 | 17 | 89 | 70 |
| 24 h | 29 | 56 | 199 | 162 | -5 | 48 | 217 | 182 | -12 | 36 | 187 | 144 |
| 36 h | 77 | 90 | 334 | 249 | 7 | 74 | 337 | 281 | -7 | 62 | 309 | 266 |
| 48 h | 119 | 119 | 474 | 363 | 24 | 100 | 469 | 396 | 4 | 87 | 425 | 349 |
| 60 h | 144 | 133 | 622 | 480 | 25 | 129 | 605 | 508 | 14 | 115 | 557 | 473 |
| 72 h | 168 | 135 | 782 | 605 | 28 | 142 | 735 | 595 | 29 | 135 | 695 | 616 |
| | No. in Subsample = 190 | | | | No. in Subsample = 169 | | | | No. in Subsample = 99 | | | |

The meridional ($\Sigma Y$) errors (Table 15) for all three categories had small values, which indicates that no north-south systematic errors exist in the three subsamples. As the zonal ($\Sigma X$) errors for the intensifying storms decrease nearly linearly from 24 h (46 km) to 72 h (-54 km), the NTCM position is initially east of the best-track longitude ("slow" for east to west-moving storms), and becomes west of the best track by 72 h. This may be a function of the initial slow bias of the NTCM, which would cause the point of recurvature to be forecast too late (Sandgathe, 1985). By contrast, the rapidly intensifying storms have a small and nearly constant (from 61 to 34 km) zonal bias. In this case, the initial slow bias in the NTCM forecasts is carried throughout the forecast period. A statistical scheme to remove the initial slow bias of the NTCM should result in a reduction in errors.

The CLIPER mean, and especially the median forecast errors (Table 16) have smaller differences among the three categories. For example, the median forecast errors at 72 h are 605, 595 and 616 km for the weakening, intensifying and rapidly intensifying storms. The relatively small differences in forecast errors between categories is seen at the 12- through 60-h forecast periods as well. In addition, the mean and median forecast errors for each category are within 35 km of the total error statistics (Table 4) at every time period except 72 h, when the mean forecast error for the weakening category is 52 km larger than the total sample mean. This result indicates that the CLIPER forecasts are not affected by changes in the past 12-h intensity trend.

Compared to the CLIPER errors, the NTCM error statistics all indicate that the NTCM has much more skill at the 36- to 72-h periods for both intensifying and rapidly intensifying categories. For example, the NTCM median and mean forecast errors at 72 h are 142 and 127 km lower than the CLIPER in the rapidly intensifying category. On the other hand, the median 72-h forecast error for the NTCM is 28 km higher than the CLIPER for the weakening category. Since the NTCM mean forecast error at 72 h for weakening storms is 120 km smaller than the CLIPER error, the NTCM evidently has fewer very large errors in its forecasts compared to CLIPER, which has a slightly lower median forecast error at 72 h.

In summary, each of the error measures suggests that the NTCM is much more skillful in forecasting intensifying storms (both slow and rapid) than weakening storms. The marked difference between rapid intensifiers and weakening storms in both CT/AT M scores and mean/median forecast errors suggest that the performance of the NTCM is significantly affected by the past 12-h intensity trend as well as the initial intensity.

## F. SIZE EFFECTS

The sample of NTCM forecasts is divided by the initial size (radius of 30-kt winds) into categories of "small" (size ≤ 100 n.mi), "medium" (size 105 to 205 n.mi) and "large" (size ≥ 210 n.mi). Although the AT M scores (Table 17) do not vary much between categories, they are the lowest in the large category. In fact, these scores among the three categories vary by only four points at 72 h and 10 points at the 48 h. This suggests that the initial size parameter has a diminishing effect with time on the speed forecast (AT component) of the NTCM.

The lowest CT M scores for the NTCM are found in the small category, where the 72-h M score is more than 10 points lower than either the medium or large categories (Table 17). Notice that the largest percentages of two-class CT errors at the 48 and 72 h time periods occur in the large subsample. Inspection of the 48- and 72-h CT contingency tables (Tables A-26 and A-27) reveals that a very large number of one- and two-class errors are located in the lower left bins of the large (size > 210 n.mi) subsample. A majority of the forecasts in the lower left bin of the contingency table indicates that the NTCM forecast track falls far to the left of the best track more frequently than it does to the right of the track (68 left versus 28 right at 48 h, and 71 left versus 24 right at 72 h). Therefore, the larger the storm, the more often the NTCM forecasts the track to be to the

TABLE 17

Cross-track and along-track percent class errors and M scores
for NTCM forecasts stratified by size (radius of 30-kt winds in n. mi).

| | | Size ≤ 105 n. mi | | | | Size 110 to 205 n. mi | | | | Size ≥ 210 n. mi | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | %0 | %1 | %2 | M | %0 | %1 | %2 | M | %0 | %1 | %2 | M |
| 24 h | CT | 46.2 | 39.3 | 14.5 | 68.3 | 40.9 | 48.6 | 10.5 | 69.6 | 43.4 | 46.3 | 10.3 | 66.9 |
| | AT | 42.5 | 38.1 | 19.4 | 76.9 | 43.1 | 42.0 | 14.9 | 71.8 | 47.4 | 41.7 | 10.9 | 63.5 |
| 48 h | CT | 54.8 | 37.1 | 8.1 | 53.3 | 54.7 | 35.4 | 9.9 | 55.2 | 45.1 | 44.0 | 10.9 | 65.8 |
| | AT | 47.8 | 36.6 | 15.6 | 67.8 | 50.8 | 39.8 | 9.4 | 58.6 | 49.7 | 42.3 | 8.0 | 58.3 |
| 72 h | CT | 54.8 | 36.6 | 8.6 | 53.8 | 46.4 | 41.4 | 12.2 | 65.8 | 45.1 | 41.2 | 13.7 | 68.6 |
| | AT | 53.8 | 32.8 | 13.4 | 59.6 | 50.8 | 39.3 | 9.9 | 59.1 | 53.7 | 37.2 | 9.1 | 55.4 |
| | | No. in Subsample = 186 | | | | No. in Subsample = 181 | | | | No. in Subsample = 175 | | | |

TABLE 18

Mean (Mn), median (Md), and systematic errors (km)
for NTCM forecasts stratified by size (radius of 30-kt winds in n. mi).

| | Size ≤ 105 n. mi | | | | Size 110 to 205 n. mi | | | | Size ≥ 210 n. mi | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ΣX | ΣY | Mn | Md | ΣX | ΣY | Mn | Md | ΣX | ΣY | Mn | Md |
| 12 h | 65 | 8 | 159 | 147 | 49 | 5 | 132 | 117 | 24 | -8 | 119 | 107 |
| 24 h | 106 | 6 | 260 | 239 | 64 | -3 | 225 | 198 | 6 | -9 | 188 | 162 |
| 36 h | 96 | 12 | 340 | 291 | 44 | 2 | 300 | 273 | -7 | -2 | 260 | 232 |
| 48 h | 72 | -27 | 441 | 368 | 34 | -17 | 397 | 353 | -59 | -4 | 351 | 323 |
| 60 h | 81 | -37 | 541 | 496 | 25 | 4 | 512 | 457 | -85 | 26 | 468 | 406 |
| 72 h | 75 | -41 | 661 | 582 | 18 | 13 | 618 | 575 | -121 | 2 | 597 | 498 |
| | No. in Subsample = 186 | | | | No. in Subsample = 181 | | | | No. in Subsample = 175 | | | |

TABLE 19

Mean (Mn), medan (Md), and systematic errors (km)
for CLIPER forecasts stratified by size (radius of 30-kt winds in n. mi).

| | Size ≤ 105 n. mi | | | | Size 110 to 205 n. mi | | | | Size ≥ 210 n. mi | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ΣX | ΣY | Mn | Md | ΣX | ΣY | Mn | Md | ΣX | ΣY | Mn | Md |
| 12 h | 4 | 25 | 130 | 102 | -15 | 21 | 98 | 84 | -6 | 18 | 91 | 77 |
| 24 h | 32 | 53 | 240 | 215 | -23 | 43 | 198 | 168 | -2 | 44 | 179 | 154 |
| 36 h | 72 | 68 | 370 | 293 | -22 | 67 | 331 | 280 | 15 | 83 | 283 | 238 |
| 48 h | 108 | 83 | 510 | 414 | -21 | 88 | 478 | 389 | 34 | 119 | 380 | 334 |
| 60 h | 128 | 105 | 652 | 525 | -32 | 103 | 634 | 523 | 45 | 138 | 484 | 411 |
| 72 h | 154 | 126 | 799 | 644 | -28 | 115 | 792 | 673 | 38 | 123 | 592 | 480 |
| | No. in Subsample = 186 | | | | No. in Subsample = 181 | | | | No. in Subsample = 175 | | | |

left of the best track. A possible explanation of this bias to the left of the best track is that the NTCM tends to forecast straight tracks for large (probably recurving) storms. As a westward-moving storm begins to turn to the northwest, a straight forecast would produce large negative (left) CT components. In addition, a forecast that recurves the storm too late will also produce negative CT components. This was observed in the case of Typhoon Abby during 1983, which began to recurve around the western periphery of the subtropical ridge soon after it formed. Although the NTCM (as well as the other objective aids) continually forecast Abby to move west-northwest, this storm produced some of the largest forecast errors in this data set and many of the left of track one- and two-class CT errors in the large category (Tables A-25 through A-27).

The mean and median forecast errors of the NTCM (Table 18) seem to contradict the above findings. That is, the mean and median forecast errors are largest for the small category and decrease from the small to large categories (this applies to CLIPER as well). However, the mean and median forecast errors do not vary much among the three categories (90 km or less at all time periods) compared to the differences found between categories of the other storm-related parameters. The lower forecast errors for the large category may be due to more accurate initial positions and working-best-tracks for the large storms. This reasoning assumes that the fix accuracy for very large (or intense) tropical cyclones is higher than for small systems due to better-defined central features. While there are cases of intense storms that have very small radii of 30-kt winds, it is generally held that the size of tropical cyclones generally increases with intensity. Thus, smaller errors in initial position result in smaller errors propagated along the forecast track. In addition, the frequency of fixes is higher for very large or intense storms because the JTWC places higher priority on tasking satellite coverage and aircraft reconnaissance for such potentially destructive systems. Because of resource limitations less threatening storms often receive less coverage in terms of fix data during multiple-storm situations.

Only the zonal ($\sum X$) errors in the large category (Table 18) show a systematic change with forecast period from 24 km east of the best track to 121 km west of best track. As described above, this increase in the zonal error is interpreted as a NTCM forecast track continuing westward while the storm is tending to recurve to the north. The zonal errors for the small and medium sizes tend to be large from the initial time and do not systematically grow, which suggests difficulties with initializing the NTCM. The meridional ($\sum Y$) errors for the small storms (Table 18) have a very small systematic trend from north (8 km) to south (-41 km) of the best track position, but no systematic change for the medium and large storms.

The CLIPER mean and median forecast errors (Table 19) also indicate distinctly smaller forecast errors for the large category. The mean and median CLIPER errors at 72 h for the large storms are 200 and 164 km smaller than those for the medium storms. This sensitivity of the CLIPER to the size parameter may also be traced in part to smaller initial positioning errors. Notice that the NTCM forecast errors at 72 h are slightly larger than the CLIPER errors for the large category. By contrast, the NTCM mean and median forecast errors at 72 h for the small and medium categories are smaller than the CLIPER errors by at least 98 km (Tables 18 and 19) at all forecast intervals. This suggests that the NTCM shows a higher skill level for small and medium storms than for large storms relative to CLIPER, even though the actual error magnitudes are smaller for the large storms.

In summary, the CT M scores and contingency tables indicate that the NTCM forecast tracks for large storms are left of the best track much more often than they are to the right. In addition, the NTCM has slightly higher forecast errors at 72 h for large storms than the CLIPER, which indicates that the NTCM has little skill in this category. Although the forecast errors are slightly larger for the small and medium storms, they are much smaller than the CLIPER errors, which indicates a higher level of skill. In addition, there is a large systematic decrease in the zonal ($\sum X$) component for large storms, so that the NTCM forecast becomes farther west of the best track with forecast period.

It should be noted that the radius of 30-kt winds may not be an accurate representation of the size. The infrequency of wind field measurements make this storm-related parameter the most subjective of the five. In many cases, aircraft peripheral data or synoptic data from ships or islands close to the storm are not available, and the TDO must extrapolate the size from the most recent data available, or estimate the size from satellite imagery. An objective method for determining storm size would be desirable to facilitate the use of such data in future studies.

# VI. SUMMARY AND CONCLUSIONS

Various error statistics for evaluating the effects of storm-related parameters on the NTCM are applied to a sample of 542 NTCM forecasts during 1981-1983. A new technique for computing the cross-track (CT) and along-track (AT) error components relative to CLIPER forecast positions is found to be very effective for evaluating the errors in a storm-oriented frame of reference. The best-track CT components at each forecast period are distributed normally about the respective extrapolated CLIPER tracks. The NTCM CT and AT errors are related to true storm movement (left or right, and slow or fast) by comparison in contingency tables with the verifying best-track positions. An M score is used to distill the information from each contingency table into a single penalty score. The mean and median forecast errors and the systematic errors are also calculated. The statistics of the total sample (1981 through 1983) for the western North Pacific indicate a slow bias in the NTCM forecasts, especially at the early (12 to 36 h) forecast periods.

The NTCM forecasts are evaluated within terciles for five initial storm-related parameters (latitude, longitude, intensity, intensity trend and size). For storms with initial latitudes south of 13° N, the NTCM predicts the direction and speed of storms much better than for storms north of 13° N. The forecast errors are lower for the southern storms as well. By contrast, the NTCM performs relatively poorly at 72 h for storms with initial latitudes north of 17° N. The CT errors for the northern storms were especially large at 48 and 72 h. The systematic errors and contingency tables indicate that the NTCM has a large westward and left-of-track bias, which suggests that the NTCM is slow in forecasting recurvature for storms in the northern area. The NTCM performs better for storms with initial longitudes west of 129° E. Low CT M scores (only 43.8 at 48 h) and forecast errors for the NTCM in this region are thought to be a function of the data availability of the western area relative to the areas farther east.

NTCM forecasts of storms with initial intensities between 50 and 75 kt (moderate category) are found to have much better CT/AT performance characteristics than weak or intense categories of storms. The CT contingency tables indicate the NTCM has no bias left or right of the best track in the moderate category, whereas the weak storms are more often forecast to the right of best track and intense storms to the left. In agreement with the CT/AT statistics, the forecast errors for the moderate category are also relatively small. The results support the expectation that the NTCM would perform better on storms with initial intensities more closely resembling that of the fixed-intensity bogus storm. It is therefore recommended that a variable intensity storm bogus to agree with the actual intensity be evaluated as an upgrade to the NTCM. The NTCM has lower CT and AT M scores, and lower forecast errors, for intensifying storms than for weakening storms. An initial slow bias in the NTCM forecasts tends to be carried throughout the forecast period for storms in the rapidly intensifying category.

The radius of 30-kt winds from the JTWC warnings, which is used as a measure of storm size, is a relatively subjective measure because no objective technique exists for estimating the radius in the absence of peripheral data. The NTCM forecasts for very large storms are to the left of the best track much more often than to the right. A large systematic decrease with increasing forecast period of the zonal ($\sum X$) error component also suggests that the NTCM does not show a high degree of skill in forecasting the recurvature of large systems. The NTCM shows no improvement in the mean and median forecasts errors relative to the CLIPER for the large category, despite having slightly lower errors than the small and medium categories.

These results provide the Typhoon Duty Officer valuable information about the NTCM performance with respect to various storm-related parameters. It is recommend that similar studies be conducted to provide the same information about the One-way Tropical Cyclone Model (OTCM) and other dynamic forecast aids. These results should also be used to construct of a decision tree that will provide the TDO with a real-time evaluation of each forecast aid. Such a tool might contribute to reductions in track forecast errors of these destructive cyclones.

# APPENDIX:
# CROSS-TRACK (CT) AND ALONG-TRACK (AT) CONTINGENCY TABLES AND PERCENTAGE OF ONE-, TWO- AND THREE-CLASS ERROR TABLES

Each table in the appendix contains three columns which correspond to different values of a storm-related parameter. Each column contains a three-by-three contingency table of CT or AT errors on the top row and a table of the percentage of of one-, two- and three-class errors on the bottom row. The contingency tables can be likened to a box with nine bins which contain the CT or AT error components of the NTCM forecasts compared with the best track positions. The forecasts and best-track positions are first referenced to a CLIPER track (either left, right, center or slow, fast, center) and then compared to each other in the contingency table. If, for example, an NTCM forecast is left of the CLIPER track and the best track is also left, the number of cases in the upper left bin of the CT contingency table is increased by one. This bin represents a number of zero-class errors, as do the other bins on the upper-left to lower-right diagonal. The upper-right and lower-left bins represent the number of two-class errors, and the remaining bins the one-class errors. The percentage of the class errors (with respect to the subsample in that column) are tabulated below the contingency tables. They show the percentage of CT (AT) class errors that occur left (slow), center, or right (fast) of the best track as well as the total percentage of class errors for the subsample.

The tables are organized in the following order:

I. Storm-related parameter
   A. Cross-track error components
      1. 24-h NTCM forecasts
      2. 48-h NTCM forecasts
      3. 72-h NTCM forecasts
   B. Along-track error components
      1. 24-h NTCM forecasts
      2. 48-h NTCM forecasts
      3. 72-h NTCM forecasts

TABLE A-1

Cross-track contingencies, percent class errors, and M scores for 24-h NTCM forecasts stratified by latitude

**Latitude < 13° N**

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 34 | 19 | 14 | 67 |
| C | 11 | 30 | 19 | 60 |
| R | 7 | 26 | 23 | 56 |
| Totals | 52 | 75 | 56 | 87 |

Number in Subsample = 183

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 50.8 | 28.4 | 20.9 |
| C | 50.0 | 50.0 | ---- |
| R | 41.1 | 46.4 | 12.5 |
| Totals | 47.5 | 41.0 | 11.5 |

M Score = 64.0

**Latitude 13° to 17° N**

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 21 | 26 | 16 | 63 |
| C | 10 | 24 | 19 | 53 |
| R | 7 | 24 | 30 | 61 |
| Totals | 38 | 74 | 65 | 75 |

Number in Subsample = 177

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 33.3 | 41.3 | 25.4 |
| C | 45.3 | 54.7 | ---- |
| R | 49.2 | 39.3 | 11.5 |
| Totals | 42.4 | 44.6 | 13.0 |

M Score = 70.6

**Latitude ≥ 17° N**

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 21 | 21 | 5 | 47 |
| C | 28 | 23 | 15 | 66 |
| R | 15 | 24 | 30 | 69 |
| Totals | 64 | 68 | 50 | 74 |

Number in Subsample = 182

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 44.7 | 44.7 | 10.6 |
| C | 34.9 | 65.2 | ---- |
| R | 43.5 | 34.8 | 21.7 |
| Totals | 40.7 | 48.3 | 11.0 |

M Score = 70.3

Cut Points: L < -75 km; C = -75 to 50 km; R > 50 km (Best Track relative to CLIPER)

TABLE A-2

Same as A-1, except for 48 h

## Latitude < 13° N

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 52 | 11 | 7 | 70 |
| C | 10 | 34 | 8 | 52 |
| R | 9 | 32 | 20 | 61 |
| Totals | 71 | 77 | 35 | 106 |

Number in Subsample = 183

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 74.3 | 15.7 | 10.0 |
| C | 65.4 | 34.6 | ---- |
| R | 32.8 | 52.5 | 14.8 |
| Totals | 57.9 | 33.3 | 8.8 |

M Score =. 50.8

## Latitude 13° to 17° N

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 29 | 27 | 9 | 65 |
| C | 12 | 41 | 14 | 67 |
| R | 7 | 13 | 25 | 45 |
| Totals | 48 | 81 | 48 | 95 |

Number in Subsample = 177

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 44.6 | 41.5 | 13.9 |
| C | 61.2 | 38.8 | ---- |
| R | 55.6 | 28.9 | 15.6 |
| Totals | 53.7 | 37.3 | 9.0 |

M Score = 55.3

## Latitude ≥ 17° N

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 32 | 18 | 3 | 53 |
| C | 29 | 19 | 9 | 57 |
| R | 17 | 27 | 28 | 72 |
| Totals | 78 | 64 | 40 | 79 |

Number in Subsample = 182

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 60.4 | 34.0 | 5.7 |
| C | 33.3 | 66.7 | ---- |
| R | 38.9 | 37.5 | 23.6 |
| Totals | 43.4 | 45.6 | 11.0 |

M Score = 67.6

Cut Points: L < -125 km; C = -125 to 125 km; R > 125 km (Best Track relative to CLIPER)

TABLE A-3
Same as A-1, except for 72-h.

### Latitude < 13° N

NTCM (columns) vs. Best Track (rows)

| Best Track | L | C | R | Totals |
|---|---|---|---|---|
| L | 47 | 17 | 5 | 69 |
| C | 12 | 31 | 12 | 55 |
| R | 6 | 29 | 24 | 59 |
| Totals | 65 | 77 | 41 | 102 |

Number in Subsample = 183

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 68.1 | 24.6 | 7.3 |
| C | 56.4 | 43.6 | ---- |
| R | 40.7 | 49.2 | 10.2 |
| Totals | 55.7 | 38.3 | 6.0 |

M Score = 50.3

### Latitude 13° to 17° N

NTCM (columns) vs. Best Track (rows)

| Best Track | L | C | R | Totals |
|---|---|---|---|---|
| L | 35 | 20 | 12 | 67 |
| C | 14 | 28 | 14 | 56 |
| R | 11 | 15 | 28 | 54 |
| Totals | 60 | 63 | 54 | 91 |

Number in Subsample = 177

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 52.2 | 29.9 | 17.9 |
| C | 50.0 | 50.0 | ---- |
| R | 51.9 | 27.8 | 20.4 |
| Totals | 51.4 | 35.6 | 13.0 |

M Score = 61.6

### Latitude ≥ 17° N

NTCM (columns) vs. Best Track (rows)

| Best Track | L | C | R | Totals |
|---|---|---|---|---|
| L | 21 | 21 | 2 | 44 |
| C | 30 | 25 | 7 | 62 |
| R | 26 | 24 | 26 | 76 |
| Totals | 77 | 70 | 35 | 72 |

Number in Subsample = 182

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 47.7 | 47.7 | 4.6 |
| C | 40.3 | 59.7 | ---- |
| R | 34.2 | 31.6 | 34.2 |
| Totals | 39.6 | 45.0 | 15.4 |

M Score = 75.8

Cut Points: L < -200 km; C = -200 to 200 km; R > 200 km (Best Track relative to CLIPER)

TABLE A-4

Same as A-1, except for along-track 24-h .

### Latitude < 13° N

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 39 | 16 | 8 | 63 |
| C | 27 | 17 | 10 | 54 |
| F | 28 | 13 | 25 | 66 |
| Totals | 94 | 46 | 43 | 81 |

Number in Subsample = 183

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 61.9 | 25.4 | 12.7 |
| C | 31.5 | 68.5 | ---- |
| F | 37.9 | 19.7 | 42.4 |
| Totals | 44.3 | 36.0 | 19.7 |

M Score = 75.4

### Latitude 13° to 17° N

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 32 | 12 | 4 | 48 |
| C | 37 | 20 | 4 | 61 |
| F | 29 | 25 | 14 | 68 |
| Totals | 98 | 57 | 22 | 66 |

Number in Subsample = 177

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 66.7 | 25.0 | 8.3 |
| C | 32.8 | 67.2 | ---- |
| F | 20.6 | 36.8 | 42.6 |
| Totals | 37.3 | 44.1 | 18.6 |

M Score = 81.3

### Latitude ≥ 17° N

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 49 | 13 | 2 | 64 |
| C | 29 | 32 | 11 | 72 |
| F | 11 | 23 | 12 | 46 |
| Totals | 89 | 68 | 25 | 93 |

Number in Subsample = 182

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 76.6 | 20.3 | 3.1 |
| C | 44.4 | 55.6 | ---- |
| F | 26.1 | 50.0 | 23.9 |
| Totals | 51.1 | 41.8 | 7.1 |

M Score = 56.0

Cut Points: S < -125 km; C = -125 to 15 km; F > 15 km (Best Track relative to CLIPER)

TABLE A-5

Same as A-4, except for 48 h.

## Latitude < 13° N

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 50 | 17 | 3 | 70 |
| C | 22 | 24 | 14 | 60 |
| F | 17 | 13 | 23 | 53 |
| Totals | 89 | 54 | 40 | 97 |

Number in Subsample = 183

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 71.4 | 24.3 | 4.3 |
| C | 40.0 | 60.0 | ---- |
| F | 43.4 | 24.5 | 32.1 |
| Totals | 53.0 | 36.1 | 10.9 |

M Score = 57.9

## Latitude 13° to 17° N

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 31 | 20 | 5 | 56 |
| C | 20 | 16 | 8 | 44 |
| F | 24 | 21 | 32 | 77 |
| Totals | 75 | 57 | 45 | 79 |

Number in Subsample = 177

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 55.4 | 35.7 | 8.9 |
| C | 36.4 | 63.6 | ---- |
| F | 41.6 | 27.3 | 31.2 |
| Totals | 44.6 | 39.0 | 16.4 |

M Score = 71.8

## Latitude ≥ 17° N

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 35 | 14 | 3 | 52 |
| C | 24 | 33 | 19 | 76 |
| F | 8 | 22 | 24 | 54 |
| Totals | 67 | 69 | 46 | 92 |

Number in Subsample = 182

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 67.3 | 26.9 | 5.8 |
| C | 43.4 | 56.6 | ---- |
| F | 44.4 | 40.7 | 14.8 |
| Totals | 50.6 | 43.4 | 6.0 |

M Score = 55.4

Cut Points: S < -275 km; C = -275 to -25 km; F > -25 km (Best Track relative to CLIPER)

TABLE A-6

Same as A-4, except for 72 h.

## Latitude < 13° N

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 56 | 18 | 6 | 80 |
| C | 17 | 23 | 21 | 61 |
| F | 12 | 10 | 20 | 42 |
| Totals | 85 | 51 | 47 | 99 |

Number in Subsample = 183

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 70.0 | 22.5 | 7.5 |
| C | 37.7 | 62.3 | ---- |
| F | 47.6 | 23.8 | 28.6 |
| Totals | 54.1 | 36.1 | 9.8 |

M Score = 55.7

## Latitude 13° to 17° N

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 36 | 22 | 4 | 62 |
| C | 10 | 29 | 7 | 46 |
| F | 20 | 20 | 29 | 69 |
| Totals | 66 | 71 | 40 | 94 |

Number in Subsample = 177

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 58.1 | 35.5 | 6.5 |
| C | 63.0 | 37.0 | ---- |
| F | 42.0 | 29.0 | 29.0 |
| Totals | 53.1 | 33.3 | 13.6 |

M Score = 60.5

## Latitude ≥ 17° N

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 19 | 19 | 3 | 41 |
| C | 18 | 35 | 17 | 70 |
| F | 14 | 18 | 39 | 71 |
| Totals | 51 | 72 | 59 | 93 |

Number in Subsample = 182

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 46.3 | 46.3 | 7.3 |
| C | 50.0 | 50.0 | ---- |
| F | 54.9 | 25.4 | 19.7 |
| Totals | 51.1 | 39.6 | 9.3 |

M Score = 58.2

Cut Points: S < -400 km; C = -400 to -50 km; F > -50 km (Best Track relative to CLIPER)

TABLE A-7

Same as A-1, except for cross-track 24 h stratified by longitude.

## Longitude < 129° E

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 21 | 18 | 3 | 42 |
| C | 15 | 41 | 19 | 75 |
| R | 3 | 22 | 27 | 52 |
| Totals | 39 | 81 | 49 | 89 |

Number in Subsample = 169

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 50.0 | 42.9 | 7.1 |
| C | 54.7 | 45.3 | ---- |
| R | 51.9 | 42.3 | 5.8 |
| Totals | 52.7 | 43.8 | 3.5 |

M Score = 50.8

## Longitude 129° to 140° E

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 19 | 24 | 7 | 50 |
| C | 18 | 18 | 14 | 50 |
| R | 19 | 36 | 31 | 86 |
| Totals | 56 | 78 | 52 | 68 |

Number in Subsample = 186

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 38.0 | 48.0 | 14.0 |
| C | 36.0 | 64.0 | ---- |
| R | 36.0 | 41.9 | 22.1 |
| Totals | 36.6 | 49.4 | 14.0 |

M Score = 77.4

## Longitude ≥ 140° E

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 36 | 24 | 25 | 85 |
| C | 16 | 18 | 20 | 54 |
| R | 7 | 16 | 25 | 48 |
| Totals | 59 | 58 | 70 | 79 |

Number in Subsample = 187

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 42.3 | 28.2 | 29.4 |
| C | 33.3 | 66.7 | ---- |
| R | 52.1 | 33.3 | 14.6 |
| Totals | 42.3 | 40.6 | 17.1 |

M Score = 74.8

Cut Points: L < -75 km; C = -75 to 50 km; R > 50 km (Best Track relative to CLIPER)

TABLE A-8
Same as A-7, except for 48 h.

## Longitude < 129° E

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 24 | 18 | 3 | 45 |
| C | 9 | 50 | 15 | 74 |
| R | 1 | 24 | 25 | 50 |
| Totals | 34 | 92 | 43 | 99 |

Number in Subsample = 169

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 53.3 | 40.0 | 6.7 |
| C | 67.7 | 32.4 | ---- |
| R | 50.0 | 48.0 | 2.0 |
| Totals | 58.6 | 39.0 | 2.4 |

M Score = 43.8

## Longitude 129° to 140° E

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 30 | 17 | 4 | 51 |
| C | 25 | 26 | 9 | 60 |
| R | 21 | 24 | 30 | 75 |
| Totals | 76 | 67 | 43 | 86 |

Number in Subsample = 186

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 58.8 | 33.3 | 7.8 |
| C | 43.3 | 56.7 | ---- |
| R | 40.0 | 32.0 | 28.0 |
| Totals | 46.2 | 40.3 | 13.4 |

M Score = 67.1

## Longitude ≥ 140° E

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 59 | 21 | 12 | 92 |
| C | 17 | 18 | 7 | 42 |
| R | 11 | 24 | 18 | 53 |
| Totals | 87 | 63 | 37 | 95 |

Number in Subsample = 187

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 64.1 | 22.8 | 13.0 |
| C | 42.9 | 57.1 | ---- |
| R | 34.0 | 45.3 | 20.8 |
| Totals | 50.8 | 36.9 | 12.3 |

M Score = 61.5

Cut Points: L < -125 km; C = -125 to 125 km; R > 125 km (Best Track relative to CLIPER)

TABLE A-9
Same as A-7, except for 72 h.

## Longitude < 129° E

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 20 | 27 | 5 | 52 |
| C | 13 | 35 | 11 | 59 |
| R | 4 | 29 | 25 | 58 |
| Totals | 37 | 91 | 41 | 80 |

Number in Subsample = 169

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 38.5 | 51.9 | 9.6 |
| C | 59.3 | 40.7 | ---- |
| R | 43.1 | 50.0 | 6.9 |
| Totals | 47.4 | 47.3 | 5.3 |

M Score = 57.9

## Longitude 129° to 140° E

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 26 | 18 | 4 | 48 |
| C | 27 | 24 | 13 | 64 |
| R | 26 | 21 | 27 | 74 |
| Totals | 79 | 63 | 44 | 77 |

Number in Subsample = 186

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 54.2 | 37.5 | 8.3 |
| C | 37.5 | 62.5 | ---- |
| R | 36.5 | 28.4 | 35.1 |
| Totals | 41.4 | 42.5 | 16.1 |

M Score = 74.7

## Longitude ≥ 140° E

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 57 | 13 | 10 | 80 |
| C | 16 | 25 | 9 | 50 |
| R | 13 | 18 | 26 | 57 |
| Totals | 86 | 56 | 45 | 108 |

Number in Subsample = 187

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 71.3 | 16.3 | 12.5 |
| C | 50.0 | 50.0 | ---- |
| R | 45.6 | 31.6 | 22.8 |
| Totals | 57.8 | 29.9 | 12.3 |

M Score = 54.5

Cut Points: L < -200 km; C = -200 to 200 km; R > 200 km (Best Track relative to CLIPER)

TABLE A-10
Same as A-7, except for along-track 24 h.

### Longitude < 129° E

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 35 | 21 | 2 | 58 |
| C | 38 | 18 | 13 | 69 |
| F | 21 | 12 | 9 | 42 |
| Totals | 94 | 51 | 24 | 62 |

Number in Subsample = 169

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 60.3 | 36.2 | 3.5 |
| C | 26.1 | 73.9 | ---- |
| F | 21.4 | 28.6 | 50.0 |
| Totals | 36.7 | 49.2 | 13.6 |

M Score = 76.9

### Longitude 129° to 140° E

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 47 | 6 | 0 | 53 |
| C | 34 | 26 | 6 | 66 |
| F | 27 | 30 | 10 | 67 |
| Totals | 108 | 62 | 16 | 83 |

Number in Subsample = 186

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 88.7 | 11.3 | 0.0 |
| C | 39.4 | 60.6 | ---- |
| F | 14.9 | 44.8 | 40.3 |
| Totals | 44.6 | 40.9 | 14.5 |

M Score = 69.9

### Longitude ≥ 140° E

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 38 | 14 | 12 | 64 |
| C | 21 | 25 | 6 | 52 |
| F | 20 | 19 | 32 | 71 |
| Totals | 79 | 58 | 50 | 95 |

Number in Subsample = 187

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 59.4 | 21.9 | 18.8 |
| C | 48.1 | 51.9 | ---- |
| F | 45.1 | 26.8 | 28.2 |
| Totals | 50.8 | 32.1 | 17.1 |

M Score = 66.3

Cut Points: S < -125 km; C = -125 to 15 km; F > 15 km (Best Track relative to CLIPER)

TABLE A-11

Same as A-10 except for 48 h.

### Longitude < 129° E

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 42 | 12 | 3 | 57 |
| C | 25 | 22 | 10 | 57 |
| F | 22 | 17 | 16 | 55 |
| Totals | 89 | 51 | 29 | 80 |

Number in Subsample = 169

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 73.7 | 21.1 | 5.3 |
| C | 38.6 | 61.4 | ---- |
| F | 29.1 | 30.9 | 40.0 |
| Totals | 47.3 | 37.9 | 14.8 |

M Score = 67.4

### Longitude 129° to 140° E

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 38 | 14 | 3 | 55 |
| C | 30 | 29 | 16 | 75 |
| F | 12 | 22 | 22 | 56 |
| Totals | 80 | 65 | 41 | 89 |

Number in Subsample = 186

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 69.1 | 25.5 | 5.5 |
| C | 38.7 | 61.3 | ---- |
| F | 39.3 | 39.3 | 21.4 |
| Totals | 47.9 | 44.1 | 8.0 |

M Score = 60.1

### Longitude ≥ 140° E

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 36 | 25 | 5 | 66 |
| C | 11 | 22 | 15 | 48 |
| F | 15 | 17 | 41 | 73 |
| Totals | 62 | 64 | 61 | 99 |

Number in Subsample = 187

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 54.6 | 37.9 | 7.6 |
| C | 45.8 | 54.2 | ---- |
| F | 56.2 | 23.3 | 20.6 |
| Totals | 52.9 | 36.4 | 10.7 |

M Score = 57.8

Cut Points: S < -275 km; C = -275 to -25 km; F > -25 km (Best Track relative to CLIPER)

TABLE A-12
Same as A-10 except for 72 h

## Longitude < 129° E

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 46 | 12 | 1 | 59 |
| C | 11 | 27 | 12 | 50 |
| F | 21 | 24 | 15 | 60 |
| Totals | 78 | 63 | 28 | 88 |

Number in Subsample = 169

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 78.0 | 20.3 | 1.7 |
| C | 54.0 | 46.0 | ---- |
| F | 25.0 | 40.0 | 35.0 |
| Totals | 52.1 | 34.9 | 13.0 |

M Score = 60.9

## Longitude 129° to 140° E

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 22 | 32 | 3 | 57 |
| C | 22 | 34 | 10 | 66 |
| F | 10 | 16 | 37 | 63 |
| Totals | 54 | 82 | 50 | 93 |

Number in Subsample = 186

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 38.6 | 56.1 | 5.3 |
| C | 51.5 | 48.5 | ---- |
| F | 58.7 | 25.4 | 15.9 |
| Totals | 50.0 | 43.0 | 7.0 |

M Score = 57.0

## Longitude ≥ 140° E

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 43 | 15 | 9 | 67 |
| C | 12 | 26 | 23 | 61 |
| F | 15 | 8 | 36 | 59 |
| Totals | 70 | 49 | 68 | 105 |

Number in Subsample = 187

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 64.2 | 22.4 | 13.4 |
| C | 42.6 | 57.4 | ---- |
| F | 61.0 | 13.6 | 25.4 |
| Totals | 56.2 | 31.0 | 12.8 |

M Score = 56.6

Cut Points: S < -400 km; C = -400 to -50 km; F > -50 km (Best Track relative to CLIPER)

TABLE A-13

Same as A-1, except for cross-track 24 h stratified by intensity

## Intensity ≤ 45 kts

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 24 | 23 | 22 | 69 |
| C | 11 | 21 | 18 | 50 |
| R | 10 | 24 | 29 | 63 |
| Totals | 45 | 68 | 69 | 74 |

Number in Subsample = 182

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 34.8 | 33.3 | 31.9 |
| C | 42.0 | 58.0 | ---- |
| R | 46.0 | 38.1 | 15.9 |
| Totals | 40.7 | 41.7 | 17.6 |

M Score = 76.9

## Intensity 50 to 75 kts.

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 30 | 21 | 9 | 60 |
| C | 9 | 33 | 23 | 65 |
| R | 6 | 25 | 26 | 57 |
| Totals | 45 | 79 | 58 | 89 |

Number in Subsample = 182

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 50.0 | 35.0 | 15.0 |
| C | 50.8 | 49.2 | ---- |
| R | 45.6 | 43.9 | 10.5 |
| Totals | 48.9 | 41.8 | 8.3 |

M Score = 58.4

## Intensity ≥ 80 kts.

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 22 | 22 | 4 | 48 |
| C | 29 | 23 | 12 | 64 |
| R | 13 | 25 | 28 | 66 |
| Totals | 64 | 70 | 44 | 73 |

Number in Subsample = 178

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 45.8 | 45.8 | 8.3 |
| C | 35.9 | 64.1 | ---- |
| R | 42.4 | 37.9 | 19.7 |
| Totals | 41.0 | 49.4 | 9.6 |

M Score = 68.6

Cut Points: L < -75 km; C = -75 to 50 km; R > 50 km (Best Track relative to CLIPER)

TABLE A-14

Same as A-13, except for 48 h

## Intensity ≤ 45 kts

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 31 | 21 | 14 | 66 |
| C | 12 | 29 | 13 | 54 |
| R | 10 | 27 | 12 | 62 |
| Totals | 53 | 77 | 52 | 85 |

Number in Subsample = 182

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 47.0 | 31.8 | 21.2 |
| C | 53.7 | 46.3 | ---- |
| R | 40.3 | 43.5 | 16.1 |
| Totals | 46.7 | 40.1 | 13.2 |

M Score = 66.5

## Intensity 50 to 75 kts

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 48 | 16 | 2 | 66 |
| C | 13 | 36 | 13 | 62 |
| R | 9 | 18 | 27 | 54 |
| Totals | 70 | 70 | 42 | 111 |

Number in Subsample = 182

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 72.7 | 24.2 | 3.0 |
| C | 58.1 | 41.9 | ---- |
| R | 50.0 | 33.3 | 16.7 |
| Totals | 61.0 | 33.0 | 6.0 |

M Score = 45.0

## Intensity ≥ 80 kts

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 34 | 19 | 3 | 56 |
| C | 26 | 29 | 5 | 60 |
| R | 14 | 27 | 21 | 62 |
| Totals | 74 | 75 | 29 | 84 |

Number in Subsample = 178

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 60.7 | 33.9 | 5.4 |
| C | 48.3 | 51.7 | ---- |
| R | 33.9 | 43.5 | 22.6 |
| Totals | 47.2 | 43.2 | 9.6 |

M Score = 62.4

Cut Points: L < -125 km; C = -125 to 125 km; R > 125 km (Best Track relative to CLIPER)

TABLE A-15
Same as A-13, except for 72 h

### Intensity ≤ 45 kts

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 29 | 16 | 12 | 57 |
| C | 16 | 31 | 14 | 61 |
| R | 8 | 27 | 29 | 64 |
| Totals | 53 | 74 | 55 | 89 |

Number in Subsample = 182

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 50.9 | 28.1 | 21.1 |
| C | 50.8 | 49.2 | ---- |
| R | 45.3 | 42.2 | 12.5 |
| Totals | 48.9 | 40.1 | 11.0 |

M Score = 62.1

### Intensity 50 to 75 kts

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 50 | 23 | 5 | 78 |
| C | 13 | 24 | 11 | 48 |
| R | 7 | 20 | 29 | 56 |
| Totals | 70 | 67 | 45 | 103 |

Number in Subsample = 182

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 64.1 | 29.5 | 6.4 |
| C | 50.0 | 50.0 | ---- |
| R | 51.8 | 35.7 | 12.5 |
| Totals | 56.6 | 36.8 | 6.6 |

M Score = 50.0

### Intensity ≥ 80 kts

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 24 | 19 | 2 | 45 |
| C | 27 | 29 | 8 | 64 |
| R | 28 | 21 | 20 | 69 |
| Totals | 79 | 69 | 30 | 73 |

Number in Subsample = 178

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 53.3 | 42.2 | 4.4 |
| C | 45.3 | 54.7 | ---- |
| R | 29.0 | 30.4 | 40.6 |
| Totals | 41.0 | 42.1 | 16.9 |

M Score = 75.9

Cut Points: L < -200 km; C = -200 to 200 km; R > 200 km (Best Track relative to CLIPER)

TABLE A-16

Same as A-13, except for along-track 24 h

### Intensity ≤ 45 kts

Rows: Best Track; columns: NTCM

| | S | C | F | Totals |
|---|---|---|---|---|
| S | 44 | 12 | 4 | 60 |
| C | 25 | 13 | 8 | 46 |
| F | 38 | 23 | 15 | 76 |
| Totals | 107 | 48 | 27 | 72 |

Number in Subsample = 182

| | %0 | %1 | %2 |
|---|---|---|---|
| S | 73.3 | 20.0 | 6.7 |
| C | 28.3 | 71.7 | ---- |
| F | 19.7 | 30.3 | 50.0 |
| Totals | 39.6 | 40.7 | 23.1 |

M Score = 83.5

### Intensity 50 to 75 kts

Rows: Best Track; columns: NTCM

| | S | C | F | Totals |
|---|---|---|---|---|
| S | 42 | 14 | 3 | 59 |
| C | 31 | 24 | 7 | 62 |
| F | 19 | 18 | 24 | 61 |
| Totals | 92 | 56 | 34 | 90 |

Number in Subsample = 182

| | %0 | %1 | %2 |
|---|---|---|---|
| S | 71.2 | 23.7 | 5.1 |
| C | 38.7 | 61.3 | ---- |
| F | 39.3 | 29.5 | 31.1 |
| Totals | 49.5 | 38.4 | 12.1 |

M Score = 62.6

### Intensity ≥ 80 kts

Rows: Best Track; columns: NTCM

| | S | C | F | Totals |
|---|---|---|---|---|
| S | 34 | 15 | 7 | 56 |
| C | 37 | 32 | 10 | 79 |
| F | 11 | 20 | 12 | 43 |
| Totals | 82 | 67 | 29 | 78 |

Number in Subsample = 178

| | %0 | %1 | %2 |
|---|---|---|---|
| S | 60.7 | 26.8 | 12.5 |
| C | 40.5 | 59.5 | ---- |
| F | 27.9 | 46.5 | 25.6 |
| Totals | 43.8 | 46.1 | 10.1 |

M Score = 66.3

Cut Points: S < -125 km; C = -125 to 15 km; F > 15 km (Best Track relative to CLIPER)

TABLE A-17

Same as A-16, except for 48 h

### Intensity ≤ 45 kts

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 33 | 19 | 4 | 56 |
| C | 20 | 18 | 12 | 50 |
| F | 23 | 24 | 29 | 76 |
| Totals | 76 | 61 | 45 | 80 |

Number in Subsample = 182

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 58.9 | 33.9 | 7.1 |
| C | 36.0 | 64.0 | ---- |
| F | 38.2 | 31.6 | 30.3 |
| Totals | 44.0 | 41.2 | 14.8 |

M Score = 70.8

### Intensity 50 to 75 kts

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 52 | 11 | 1 | 64 |
| C | 18 | 24 | 10 | 52 |
| F | 16 | 19 | 31 | 66 |
| Totals | 86 | 54 | 42 | 107 |

Number in Subsample = 182

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 81.3 | 17.2 | 1.6 |
| C | 46.2 | 53.8 | ---- |
| F | 47.0 | 28.8 | 24.2 |
| Totals | 58.8 | 31.9 | 9.3 |

M Score = 50.5

### Intensity ≥ 80 kts

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 31 | 21 | 6 | 58 |
| C | 28 | 31 | 19 | 78 |
| F | 10 | 13 | 19 | 42 |
| Totals | 69 | 65 | 44 | 81 |

Number in Subsample = 178

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 53.4 | 36.2 | 10.3 |
| C | 39.7 | 60.3 | ---- |
| F | 45.2 | 31.0 | 23.8 |
| Totals | 45.5 | 45.5 | 9.0 |

M Score = 63.5

Cut Points: S < -275 km; C = -275 to -25 km; F > -25 km (Best Track relative to CLIPER)

TABLE A-18
Same as A-16, except for 72 h

## Intensity ≤ 45 kts

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 39 | 18 | 7 | 64 |
| C | 18 | 26 | 12 | 56 |
| F | 18 | 17 | 27 | 62 |
| Totals | 75 | 61 | 46 | 92 |

Number in Subsample = 182

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 60.9 | 28.1 | 10.9 |
| C | 46.4 | 53.6 | ---- |
| F | 43.5 | 27.4 | 29.0 |
| Totals | 50.5 | 35.7 | 13.8 |

M Score = 63.3

## Intensity 50 to 75 kts

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 44 | 16 | 1 | 61 |
| C | 12 | 25 | 19 | 56 |
| F | 18 | 13 | 34 | 65 |
| Totals | 74 | 54 | 54 | 103 |

Number in Subsample = 182

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 72.1 | 26.2 | 1.6 |
| C | 44.6 | 55.4 | ---- |
| F | 52.3 | 20.0 | 27.7 |
| Totals | 56.6 | 33.0 | 10.4 |

M Score = 53.8

## Intensity ≥ 80 kts

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 28 | 25 | 5 | 58 |
| C | 15 | 36 | 14 | 65 |
| F | 10 | 18 | 27 | 55 |
| Totals | 53 | 79 | 46 | 91 |

Number in Subsample = 178

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 48.3 | 43.1 | 8.6 |
| C | 55.4 | 44.6 | ---- |
| F | 49.1 | 32.7 | 18.2 |
| Totals | 51.1 | 40.5 | 8.4 |

M Score = 57.3

Cut Points: S < -400 km; C = -400 to -50 km; F > -50 km (Best Track relative to CLIPER)

TABLE A-19

Same as A-1, except for stratified by past 12-h intensiy change (Δ Intensity).

## Δ Intensity ≤ 0 kt

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 36 | 19 | 14 | 69 |
| C | 22 | 27 | 15 | 64 |
| R | 9 | 23 | 25 | 57 |
| Totals | 67 | 69 | 54 | 88 |

Number in Subsample = 190

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 52.2 | 27.5 | 20.3 |
| C | 42.2 | 57.8 | ---- |
| R | 43.9 | 40.4 | 15.8 |
| Totals | 46.3 | 41.6 | 12.1 |

M Score = 65.8

## Δ Intensity 5 to 10 kt

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 21 | 14 | 12 | 47 |
| C | 14 | 21 | 20 | 55 |
| R | 15 | 23 | 29 | 67 |
| Totals | 50 | 58 | 61 | 71 |

Number in Subsample = 169

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 44.7 | 29.8 | 25.5 |
| C | 38.2 | 61.8 | ---- |
| R | 43.3 | 34.3 | 22.4 |
| Totals | 42.0 | 42.0 | 16.0 |

M Score = 74.0

## Δ Intensity ≥ 15 kt

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 11 | 15 | 4 | 30 |
| C | 8 | 15 | 14 | 37 |
| R | 1 | 14 | 17 | 32 |
| Totals | 20 | 44 | 35 | 43 |

Number in Subsample = 99

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 36.7 | 50.0 | 13.3 |
| C | 40.5 | 59.5 | ---- |
| R | 53.1 | 43.8 | 3.1 |
| Totals | 43.4 | 51.5 | 5.1 |

M Score = 61.7

Cut Points: L < -75 km; C = -75 to 50 km; R > 50 km (Best Track relative to CLIPER)

TABLE A-20

Same as A-19, except for 48 h

### Δ Intensity ≤ 0 kt

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 49 | 18 | 9 | 76 |
| C | 20 | 27 | 11 | 58 |
| R | 10 | 26 | 20 | 56 |
| Totals | 79 | 71 | 40 | 96 |

Number in Subsample = 190

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 64.5 | 23.7 | 11.8 |
| C | 46.6 | 53.4 | ---- |
| R | 35.7 | 46.4 | 17.9 |
| Totals | 50.5 | 39.5 | 10.0 |

M Score = 59.5

### Δ Intensity 5 to 10 kt

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 32 | 14 | 5 | 51 |
| C | 17 | 28 | 12 | 57 |
| R | 12 | 22 | 27 | 61 |
| Totals | 61 | 61 | 44 | 87 |

Number in Subsample = 169

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 62.7 | 27.5 | 9.8 |
| C | 49.1 | 50.9 | ---- |
| R | 44.3 | 36.1 | 19.7 |
| Totals | 51.5 | 38.5 | 10.0 |

M Score = 58.5

### Δ Intensity ≥ 15 kt

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 20 | 10 | 2 | 32 |
| C | 7 | 21 | 4 | 32 |
| R | 5 | 16 | 14 | 35 |
| Totals | 32 | 47 | 20 | 55 |

Number in Subsample = 99

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 62.5 | 31.3 | 6.3 |
| C | 65.6 | 34.4 | ---- |
| R | 40.0 | 45.7 | 14.3 |
| Totals | 55.6 | 37.4 | 7.1 |

M Score = 51.6

Cut Points: L < -125 km; C = -125 to 125 km; R > 125 km (Best Track relative to CLIPER)

TABLE A-21
Same as A-19, except for 72 H

### Δ Intensity ≤ 0 kt

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 41 | 20 | 12 | 73 |
| C | 22 | 25 | 14 | 61 |
| R | 14 | 24 | 18 | 56 |
| Totals | 77 | 69 | 44 | 84 |

Number in Subsample = 190

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 56.2 | 27.4 | 16.4 |
| C | 41.0 | 59.0 | ---- |
| R | 32.1 | 42.9 | 25.0 |
| Totals | 44.2 | 42.1 | 13.7 |

M Score = 69.5

### Δ Intensity 5 to 10 kt

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 34 | 14 | 5 | 53 |
| C | 13 | 24 | 9 | 46 |
| R | 15 | 23 | 32 | 70 |
| Totals | 62 | 61 | 46 | 90 |

Number in Subsample = 169

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 64.2 | 26.4 | 9.4 |
| C | 52.2 | 47.8 | ---- |
| R | 45.7 | 32.9 | 21.4 |
| Totals | 53.3 | 34.9 | 11.8 |

M Score = 58.5

### Δ Intensity ≥ 15 kt

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 19 | 11 | 1 | 31 |
| C | 9 | 19 | 5 | 33 |
| R | 8 | 10 | 17 | 35 |
| Totals | 36 | 40 | 23 | 55 |

Number in Subsample = 99

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 61.3 | 35.5 | 3.2 |
| C | 57.6 | 42.4 | ---- |
| R | 48.6 | 28.6 | 22.9 |
| Totals | 55.6 | 35.3 | 9.1 |

M Score = 53.5

Cut Points: L < -200 km; C = -200 to 200 km; R > 200 km (Best Track relative to CLIPER)

TABLE A-22

Same as A-19, except for along-track 24 h

## Δ Intensity ≤ 0 kt

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 34 | 17 | 5 | 56 |
| C | 32 | 25 | 10 | 67 |
| F | 33 | 18 | 16 | 67 |
| Totals | 99 | 60 | 31 | 75 |

Number in Subsample = 190

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 60.7 | 30.4 | 8.9 |
| C | 37.3 | 62.7 | ---- |
| F | 23.9 | 26.9 | 49.3 |
| Totals | 39.5 | 40.5 | 20.0 |

M Score = 80.5

## Δ Intensity 5 to 10 kt

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 43 | 12 | 5 | 60 |
| C | 26 | 26 | 5 | 57 |
| F | 18 | 20 | 14 | 52 |
| Totals | 87 | 58 | 24 | 83 |

Number in Subsample = 169

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 71.7 | 20.0 | 8.3 |
| C | 45.6 | 54.4 | ---- |
| F | 26.9 | 38.5 | 34.6 |
| Totals | 49.1 | 37.3 | 13.6 |

M Score = 64.5

## Δ Intensity ≥ 15 kt

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 20 | 4 | 3 | 27 |
| C | 25 | 12 | 8 | 45 |
| F | 8 | 9 | 10 | 27 |
| Totals | 53 | 25 | 21 | 42 |

Number in Subsample = 99

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 74.1 | 14.8 | 11.1 |
| C | 26.7 | 73.3 | ---- |
| F | 37.0 | 33.3 | 29.6 |
| Totals | 42.4 | 46.5 | 11.1 |

M Score = 68.7

Cut Points: S < -125 km; C = -125 to 15 km; F > 15 km (Best Track relative to CLIPER)

TABLE A-23
Same as A-22, except for 48 h

Best Track (rows) vs. NTCM (columns)

| | Δ Intensity ≤ 0 kt | | | | Δ Intensity 5 to 10 kt | | | | Δ Intensity ≥ 15 kt | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | S | C | F | Totals | S | C | F | Totals | S | C | F | Totals |
| S | 37 | 19 | 5 | 61 | 40 | 16 | 4 | 60 | 22 | 7 | 0 | 29 |
| C | 24 | 27 | 13 | 64 | 20 | 24 | 9 | 53 | 13 | 17 | 12 | 42 |
| F | 24 | 20 | 21 | 65 | 13 | 18 | 25 | 56 | 6 | 8 | 14 | 28 |
| Totals | 85 | 66 | 39 | 85 | 73 | 58 | 38 | 89 | 41 | 32 | 26 | 53 |
| Number in Subsample | 190 | | | | 169 | | | | 99 | | | |

Best Track (rows)

| | Δ Intensity ≤ 0 kt | | | Δ Intensity 5 to 10 kt | | | Δ Intensity ≥ 15 kt | | |
|---|---|---|---|---|---|---|---|---|---|
| | %0 | %1 | %2 | %0 | %1 | %2 | %0 | %1 | %2 |
| S | 60.7 | 31.2 | 8.2 | 66.7 | 26.7 | 6.7 | 75.9 | 24.1 | 0.0 |
| C | 42.2 | 57.8 | ---- | 45.3 | 54.7 | ---- | 40.5 | 59.5 | ---- |
| F | 32.3 | 30.8 | 36.9 | 44.6 | 32.1 | 23.2 | 50.0 | 28.6 | 21.4 |
| Totals | 44.7 | 40.0 | 15.3 | 52.7 | 37.3 | 10.0 | 53.5 | 40.4 | 6.1 |
| M Score | 70.6 | | | 57.3 | | | 52.6 | | |

Cut Points: S < -275 km; C = -275 to -25 km; F > -25 km (Best Track relative to CLIPER)

TABLE A-24
Same as A-22, except for 72 h

## Δ Intensity ≤ 0 kt

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 33 | 22 | 5 | 60 |
| C | 21 | 35 | 10 | 66 |
| F | 24 | 16 | 24 | 64 |
| Totals | 78 | 73 | 39 | 92 |

Number in Subsample = 190

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 55.0 | 36.7 | |
| C | 53.0 | 47.0 | ---- |
| F | 37.5 | 25.0 | 37.5 |
| Totals | 48.4 | 36.3 | 15.3 |

M Score = 66.9

## Δ Intensity 5 to 10 kt

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 37 | 19 | 5 | 61 |
| C | 12 | 27 | 20 | 59 |
| F | 8 | 13 | 28 | 49 |
| Totals | 57 | 59 | 53 | 92 |

Number in Subsample = 169

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 60.7 | 31.1 | 8.2 |
| C | 45.8 | 54.2 | ---- |
| F | 57.1 | 26.5 | 16.3 |
| Totals | 54.4 | 37.9 | 7.7 |

M Score = 53.3

## Δ Intensity ≥ 15 kt

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 22 | 13 | 1 | 36 |
| C | 4 | 16 | 8 | 28 |
| F | 7 | 10 | 18 | 35 |
| Totals | 33 | 39 | 27 | 56 |

Number in Subsample = 99

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 61.1 | 36.1 | 2.8 |
| C | 57.1 | 42.9 | ---- |
| F | 51.4 | 28.6 | 20.0 |
| Totals | 56.6 | 35.3 | 8.1 |

M Score = 51.5

Cut Points: S < -400 km; C = -400 to -50 km; F > -50 km (Best Track relative to CLIPER)

TABLE A-25

Same as A-1, except for cross-track 24 h stratified by size (radius of 30-kt winds in n.mi).

### Size ≤ 105 n.mi

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 34 | 26 | 16 | 76 |
| C | 9 | 27 | 19 | 55 |
| R | 11 | 19 | 25 | 55 |
| Totals | 54 | 72 | 60 | 86 |

Number in Subsample = 186

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 44.7 | 34.2 | 21.1 |
| C | 49.1 | 50.9 | ---- |
| R | 45.5 | 34.5 | 20.0 |
| Totals | 46.2 | 39.3 | 14.5 |

M Score = 68.3

### Size 110 to 205 n.mi

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 21 | 20 | 14 | 55 |
| C | 15 | 29 | 24 | 68 |
| R | 5 | 29 | 24 | 58 |
| Totals | 41 | 78 | 62 | 74 |

Number in Subsample = 181

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 38.2 | 36.4 | 25.5 |
| C | 42.6 | 57.4 | ---- |
| R | 41.4 | 50.0 | 8.6 |
| Totals | 40.9 | 48.6 | 10.5 |

M Score = 69.6

### Size ≥ 210 n.mi

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 21 | 20 | 5 | 46 |
| C | 25 | 21 | 10 | 56 |
| R | 13 | 26 | 34 | 73 |
| Totals | 59 | 67 | 49 | 76 |

Number in Subsample = 175

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 45.7 | 43.5 | 10.9 |
| C | 37.5 | 62.5 | ---- |
| R | 46.6 | 35.6 | 17.8 |
| Totals | 43.4 | 46.3 | 10.3 |

M Score = 66.9

Cut Points: L < -75 km; C = -75 to 50 km; R > 50 km (Best Track relative to CLIPER)

TABLE A-26
Same as A-25, except for 48 h

## Size ≤ 105 n.mi

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 44 | 20 | 6 | 70 |
| C | 12 | 33 | 15 | 60 |
| R | 9 | 22 | 25 | 56 |
| Totals | 65 | 75 | 46 | 102 |

Number in Subsample = 186

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 62.9 | 28.6 | 8.6 |
| C | 55.0 | 45.0 | ---- |
| R | 44.6 | 39.3 | 16.1 |
| Totals | 54.8 | 37.1 | 8.1 |

M Score = 53.3

## Size 110 to 205 n.mi

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 34 | 16 | 10 | 60 |
| C | 14 | 41 | 11 | 66 |
| R | 8 | 23 | 24 | 55 |
| Totals | 56 | 80 | 45 | 99 |

Number in Subsample = 181

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 56.7 | 26.7 | 16.7 |
| C | 62.1 | 37.9 | ---- |
| R | 43.6 | 41.8 | 14.5 |
| Totals | 54.7 | 35.4 | 9.9 |

M Score = 55.2

## Size ≥ 210 n.mi

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 35 | 20 | 3 | 58 |
| C | 25 | 20 | 5 | 50 |
| R | 16 | 27 | 24 | 67 |
| Totals | 76 | 67 | 32 | 79 |

Number in Subsample = 175

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 60.3 | 34.5 | 5.2 |
| C | 40.0 | 60.0 | ---- |
| R | 35.8 | 40.3 | 23.9 |
| Totals | 45.1 | 44.0 | 10.9 |

M Score = 65.8

Cut Points: L < -125 km; C = -125 to 125 km; R > 125 km (Best Track relative to CLIPER)

TABLE A-27
Same as A-25, except for 72 h

## Size ≤ 105 n.mi

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 45 | 18 | 9 | 72 |
| C | 16 | 27 | 9 | 52 |
| R | 7 | 25 | 30 | 62 |
| Totals | 68 | 70 | 48 | 102 |

Number in Subsample = 186

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 62.5 | 25.0 | 12.5 |
| C | 51.9 | 48.1 | ---- |
| R | 48.4 | 40.3 | 11.3 |
| Totals | 54.8 | 36.6 | 8.6 |

M Score = 53.8

## Size 110 to 205 n.mi

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 34 | 24 | 9 | 67 |
| C | 11 | 24 | 17 | 52 |
| R | 13 | 23 | 26 | 62 |
| Totals | 58 | 71 | 52 | 84 |

Number in Subsample = 181

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 50.7 | 35.8 | 13.4 |
| C | 46.2 | 53.8 | ---- |
| R | 41.9 | 37.1 | 21.0 |
| Totals | 46.4 | 41.4 | 12.2 |

M Score = 65.8

## Size ≥ 210 n.mi

| Best Track \ NTCM | L | C | R | Totals |
|---|---|---|---|---|
| L | 24 | 16 | 1 | 41 |
| C | 29 | 33 | 7 | 69 |
| R | 23 | 20 | 22 | 65 |
| Totals | 76 | 69 | 30 | 79 |

Number in Subsample = 175

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| L | 58.5 | 39.0 | 2.4 |
| C | 47.8 | 52.2 | ---- |
| R | 33.8 | 30.8 | 35.4 |
| Totals | 45.1 | 41.2 | 13.7 |

M Score = 68.6

Cut Points: L < -200 km; C = -200 to 200 km; R > 200 km (Best Track relative to CLIPER)

TABLE A-28

Same as A-25, except for along-track 24 h

### Size ≤ 105 n.mi

| Best Track | NTCM S | NTCM C | NTCM F | Totals |
|---|---|---|---|---|
| S | 46 | 13 | 5 | 64 |
| C | 27 | 12 | 9 | 48 |
| F | 31 | 22 | 21 | 74 |
| Totals | 104 | 47 | 35 | 79 |

Number in Subsample = 186

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 71.9 | 20.3 | 7.8 |
| C | 25.0 | 75.0 | ---- |
| F | 28.4 | 29.7 | 41.9 |
| Totals | 42.5 | 38.1 | 19.4 |

M Score = 76.9

### Size 110 to 205 n.mi

| Best Track | NTCM S | NTCM C | NTCM F | Totals |
|---|---|---|---|---|
| S | 39 | 14 | 3 | 59 |
| C | 40 | 22 | 6 | 68 |
| F | 24 | 16 | 17 | 57 |
| Totals | 103 | 52 | 26 | 78 |

Number in Subsample = 181

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 69.6 | 25.0 | 5.4 |
| C | 32.4 | 67.6 | ---- |
| F | 29.8 | 28.1 | 42.1 |
| Totals | 43.1 | 42.0 | 14.9 |

M Score = 71.8

### Size ≥ 210 n.mi

| Best Track | NTCM S | NTCM C | NTCM F | Totals |
|---|---|---|---|---|
| S | 35 | 14 | 6 | 55 |
| C | 26 | 35 | 10 | 71 |
| F | 13 | 23 | 13 | 49 |
| Totals | 74 | 72 | 29 | 83 |

Number in Subsample = 175

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 63.6 | 25.5 | 10.9 |
| C | 49.3 | 50.7 | ---- |
| F | 26.5 | 46.9 | 26.5 |
| Totals | 47.4 | 41.7 | 10.9 |

M Score = 63.5

Cut Points: S < -125 km; C = -125 to 15 km; F > 15 km (Best Track relative to CLIPER)

TABLE A-29
Same as A-28, except for 48 h

## Size ≤ 105 n.mi

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 40 | 20 | 4 | 64 |
| C | 18 | 18 | 10 | 46 |
| F | 25 | 20 | 31 | 76 |
| Totals | 83 | 58 | 45 | 89 |

Number in Subsample = 186

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 62.5 | 31.3 | 6.3 |
| C | 39.1 | 60.9 | ---- |
| F | 40.8 | 26.3 | 32.9 |
| Totals | 47.8 | 36.6 | 15.6 |

M Score = 67.8

## Size 110 to 205 n.mi

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 43 | 19 | 1 | 63 |
| C | 22 | 29 | 11 | 62 |
| F | 16 | 20 | 20 | 56 |
| Totals | 81 | 68 | 32 | 92 |

Number in Subsample = 181

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 68.3 | 30.2 | 1.6 |
| C | 46.8 | 53.2 | ---- |
| F | 35.7 | 35.7 | 28.6 |
| Totals | 50.8 | 39.8 | 9.4 |

M Score = 58.6

## Size ≥ 210 n.mi

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 33 | 12 | 6 | 51 |
| C | 26 | 26 | 20 | 72 |
| F | 8 | 16 | 28 | 52 |
| Totals | 67 | 54 | 54 | 87 |

Number in Subsample = 175

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 64.7 | 23.5 | 11.8 |
| C | 36.1 | 63.9 | ---- |
| F | 53.8 | 30.8 | 15.4 |
| Totals | 49.7 | 42.3 | 8.0 |

M Score = 58.3

Cut Points: S < -275 km; C = -275 to -25 km; F > -25 km (Best Track relative to CLIPER)

TABLE A-30
Same as A-28, except for 72 h.

**Size ≤ 105 n.mi**

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 43 | 17 | 7 | 67 |
| C | 16 | 28 | 15 | 59 |
| F | 18 | 13 | 29 | 60 |
| Totals | 77 | 58 | 51 | 100 |

Number in Subsample = 186

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 64.2 | 25.4 | 10.4 |
| C | 47.5 | 52.5 | ---- |
| F | 48.3 | 21.7 | 30.0 |
| Totals | 53.8 | 32.8 | 13.4 |

M Score = 59.6

**Size 110 to 205 n.mi**

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 43 | 28 | 2 | 73 |
| C | 11 | 30 | 13 | 54 |
| F | 16 | 19 | 19 | 54 |
| Totals | 70 | 77 | 34 | 92 |

Number in Subsample = 181

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 58.9 | 38.4 | 2.7 |
| C | 55.6 | 44.4 | ---- |
| F | 35.2 | 35.2 | 29.6 |
| Totals | 50.8 | 39.3 | 9.9 |

M Score = 59.1

**Size ≥ 210 n.mi**

| Best Track \ NTCM | S | C | F | Totals |
|---|---|---|---|---|
| S | 25 | 14 | 4 | 43 |
| C | 18 | 29 | 17 | 64 |
| F | 12 | 16 | 40 | 68 |
| Totals | 55 | 59 | 61 | 94 |

Number in Subsample = 175

| Best Track | %0 | %1 | %2 |
|---|---|---|---|
| S | 58.1 | 32.6 | 9.3 |
| C | 45.3 | 54.7 | ---- |
| F | 58.8 | 23.5 | 17.6 |
| Totals | 53.7 | 37.2 | 9.1 |

M Score = 55.4

Cut Points: S < -400 km; C = -400 to -50 km; F > -50 km (Best Track relative to CLIPER)

## LIST OF REFERENCES

COMNAVOCEANCOM, 1984: Letter, Ser. 3/387, 20 July 1984 to CINCPACFLT re. tropical cyclone track forecast accuracy.

Elsberry, R. L., 1979: Applications of tropical cyclone models. Bulletin of the American Meteorological Society, 60, 750-762.

Elsberry, R. L., 1983: Recent developments in tropical cyclone track forecasting. Proceedings of the CCNA-AIT Joint Seminar on Monsoon and Tropical Meteorology. Sponsored by the Coordination Council for North American Affairs - The American Institute in Taiwan, pp. 89-98.

Elsberry, R. L., 1984: A proposal for an improved tropical cyclone warning system. Unpublished manuscript, Department of Meteorology, Naval Postgraduate School, Monterey, CA, April, 41 pp.

Elsberry, R. L., and J. E. Peak, 1986: An evaluation of tropical cyclone forecast aids based on cross-track and along-track components. Monthly Weather Review, 114, 156-164.

Fiorino, M., 1985: A review of the dynamic tropical cyclone forecast models developed by the U. S. Navy. Appendix F of Elsberry, R. L., and M. Fiorino, NAVENVPREDRSHFAC Technical Report TR 85-03, 152 pp.

Fiorino, M. E., J. Harrison and D. G. Marks, 1982: A comparison of the performance of two operational dynamic tropical cyclone models. Monthly Weather Review, 110, 651-656.

Harrison, E. J., Jr., 1973: Three-dimensional numerical simulations of tropical systems utilizing nested finite grids. Journal of the Atmospheric Sciences, 30, 1528-1543.

Harrison, E. J., Jr., 1981: Initial results from the Navy two-way interactive nested tropical cyclone model. Monthly Weather Review, 109, 173-177.

Harrison, E. J., Jr. and M. E. Fiorino, 1982: A comprehensive test of the Navy nested tropical cyclone model. Monthly Weather Review, 110, 645-650.

Neumann, C. J., and J. M. Pelissier, 1981: Models for the prediction of tropical cyclone motions over the North Atlantic: An operational evaluation. Monthly Weather Review, 109, 522-538.

Peak, J. E. and R. L. Elsberry, 1982: A simplified statistical post-processing technique for adjusting tropical cyclone tracks. Papers in Meteorological Research, 5, 1-14.

Peak , J. E. and R. L. Elsberry, 1984: Dynamical-statistical model forecasts of southern hemisphere tropical cyclones. Monthly Weather Review, 112, 717-724.

Peak, J. E. and R. L. Elsberry, 1985: Objective selection of optimum tropical cyclone guidance using a decision-tree methodology. Preprints, the Technical Conference on Hurricanes and Tropical Meteorology, American Meteorological Society, Boston, 97-98.

Preisendorfer, R. W., and C. D. Mobley, 1982: Data intercomparison theory, II. PMEL/NOAA Technical Memorandum, 91 pp.

Sandgathe, S. A., 1985: Operational considerations for the design of the advanced tropical cyclone model. Appendix A of Elsberry, R. L., and M. Fiorino, NAVENVPREDRSHFAC Technical Report TR 85-03, 152 pp.

Thompson, W. J., R. L. Elsberry and R. G. Read, 1980: An analysis of eastern North Pacific tropical cyclone forecast errors. Monthly Weather Review, 109, 1930-1938.

Xu, Y., and C.J. Neumann, 1985: A statistical model for the prediction of western North Pacific tropical cyclone motion (WPCLPR). NOAA Technical Memorandum, NWS-NHC 28, National Hurricane Center, Miami, Fl, 30 pp.

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